THE UNIVERSITY OF MANITOBA

THE BIOAVAILABILITY OF PHOSPHORUS FROM CANOLA MEAL IN COMPARISON WITH AN INORGANIC PHOSPHORUS SOURCE AND SOYBEAN MEAL

by

ROSE CECILIA OMOLE

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Abstract

Forty-two male Holstein calves were randomly assigned in a split-plot design to four dietary treatments. The dietary treatments consisted of a basal diet with 0.25% phosphorus (P) and experimental diets supplemented with canola meal (samples A, B, C, D, E) or Biophos to provide P levels of 0.32, 0.36 and 0.40%. All diets were isocaloric; however, added levels of canola meal increased crude protein levels. Dietary protein level varied from 14 to 18% (DM basis). Dietary treatments were arranged in a 3X2 factorial. Calves were fed whole milk for four weeks plus ad libitum calf starter. The calves were placed on test at 6 weeks of age for a ten-week period. Feed intake, weight gain, feed per kg gain, plasma inorganic P, bone ash, bone P, bone Ca and the breaking force of the eighth and ninth ribs were the response criteria used to measure P availability. Dry matter consumption, weight gain and feed per kg gain were not affected by dietary P level ($p > 0.1$). Supplementation with P increased plasma P ($p < 0.05$). Each increase in P level with canola meal resulted in an increase in plasma P level ($p < 0.05$). The first level of supplementary Biophos resulted in an increase in plasma P level ($p < 0.05$) with no differences among levels of added Biophos. The breaking force, bone ash and bone P content of the eighth and ninth

ribs were not significantly affected by P levels ($p > 0.1$). Based on blood P response to an increased dietary level of P, availability of P from canola meal was at least equal to the inorganic P source. In situ P disappearance in the rumen was significantly ($p < 0.05$) lower for SBM compared with canola meal samples B, D, and E at 12 and 16 h of rumen fermentation. From the lower gastrointestinal tract, the in situ P disappearance was not significantly ($p > 0.05$) different between SBM and CM when pepsin HCl predigestion was used.

Dedication

To my husband Collins and daughters Biola and Doyin, for patience and understanding throughout the study.

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Introduction

The increasing cost of phosphorus supplements has intensified the need for evaluation of various supplemental phosphorus sources that can be utilized economically in ruminant diets. Rapeseed is an important oilseed crop in Canada (Bell 1982) and the meal from crushed rapeseed is being used extensively as a protein supplement in dairy and beef diets. "Canola" designates cultivars of rapeseed low in erucic acid and glucosinolates (Bell 1982, 1984). Rapeseed meal when used as a protein supplement contains a relatively high level of phosphorus (Kirby and Nelson 1988, Nwokolo and Bragg 1980) and if available increases the economic value of the meal.

Canola meal contains 0.78 percent phytin phosphorus (Kirby and Nelson 1988). Although, the assumption has been made that canola meal phosphorus is available to ruminants, no research has been carried out on the availability to ruminants.

Phosphorus is a major nutrient needed for adequate body growth (Miller 1979, Underwood 1981). Using *in vitro* techniques, Chicco et al. 1965, Hall et al. 1961, Komisarczuk et al. 1985 and Milton and Ternouth 1984 reported that 30-80 mg l^{-1} of phosphorus in buffered ruminal fluid was necessary for microbial metabolism.

Phosphorus deficiency depresses growth, appetite and feed efficiency (Call et al. 1978 and Little 1968).

The objective of this study was to evaluate the availability of canola meal phosphorus for growing calves in comparison with an inorganic phosphorus source and to measure the in situ disappearance of phosphorus from canola meal in the rumen and the lower gastrointestinal tract.

Review of Literature

The Absorption of Phosphorus

The absorption of phosphorus occurs principally from the upper small intestine where the pH is acidic (Ben-Ghedalia et al. 1975, Grace et al. 1974, Kay and Pfeffer 1970 and Pfeffer et al. 1970). The amount of dietary phosphorus absorbed was proportional to the intake as long as the calcium:phosphorus ratio was between 0.8:1 and 6:1 (Lueker and Lofgreen 1961). Although, little is known on the actual absorptive process (es) involved in ruminants, it has been shown that phosphorus is absorbed as the HPO_4^{2-} and $H_2PO_4^-$ ions. In cattle limited absorption of phosphorus occurs in the omasum (Banks and Smith 1984, and Smith and Edrise 1978). Smith (1984) postulated that absorption in the omasum might be due to the large surface area. In monogastrics the absorption of phosphorus in the small intestine consists of an active process that is readily saturable and passive absorption that tends to predominate at high luminal phosphorus concentration (Harrison and Harrision 1961). Schneider et al. (1985) fed 0.72 or 4.5g P kg^{-1} dry matter to young sheep and defined absorption using a primary and secondary compartmental modelling technique. Using radiotracer techniques, they observed no differences in primary absorption which suggested a saturable mechanism.

In ruminants the kidney is not the major site of P excretion. Evidence suggests that the salivary glands play a role in P homeostasis. Clark et al. (1973) infused 3.38g of KH_2PO_4 intravenously into sheep fed a roughage diet and at the same time introduced Cr-EDTA as an unabsorbable marker into the rumen to give an estimate of endogenous P secreted into the gastrointestinal tract. They observed a small increase in urinary P excretion compared with a large increase in fecal P, 12h after the infusion. This suggested that the additional P excreted in faeces entered the gastrointestinal tract. Schneider et al. (1982) measured P absorption in mature sheep fed a roughage diet using tracer techniques and a four compartmental modelling technique. Cr-EDTA was introduced into the abomasum to measure endogenous P secretion. The intravenous infusion of 1.5-2.0g day^{-1} of NaH_2PO_4 resulted in a marked increase in the excretion of P in faeces. They suggested that the observed increase in total endogenous secretion of P resulted in the additional P being excreted in faeces.

Tomas and Somers (1974) reported increased urine levels and lower fecal P levels following parotid gland ligation which seemed to suggest that the salivary glands are involved in determination of fecal P excretion. Tomas (1974) fed sheep finely ground diets and reported a higher level of P in the urine compared to those fed a coarsely ground diet. Thus the physical nature of the diet is important, since finely ground, pelleted or highly digestible diets reduce salivary flow rate of P (Putnam et al. 1966 and Wilson and Tribe 1963). Recently, Scott and Buchan (1987) reported decreased salivary flow rate in sheep fed 1 kg day $^{-1}$ of a pelleted grass diet in comparison with a coarsely ground hay. These differences in flow rate accounted for the higher urinary excretion of P with the grass diet.

Matsui et al. (1984) recently reported increased salivary secretion of P in thyroidectomized sheep infused with calcitonin at a physiological dose rate. Although, parathyroid hormone and 1, 25 dihydroxyvitamin D_3 have been shown to increase P absorption in the gut (Braithwaite 1978, 1980) the exact mechanism by which this is mediated remains unclear.

Coppock et al. (1972) and Preston and Pfander (1964) found plasma inorganic P was directly correlated with P level in the diet. Low blood inorganic P levels may lead to disturbances in intracellular metabolism which may consequently effect a reduction in food intake (Milton and Ternouth 1985).

Methods of Determining Phosphorus Availability

Various methods have been reported for determining the availability of dietary minerals. Radioisotopes dilution techniques give the relative absorption of minerals from the total digestive tract. Lofgreen (1960) used an isotope dilution technique which involved a subcutaneous injection of P^{32} given to mature wethers at a constant feed intake of about 800g P day^{-1} with blood and feaces being collected after a lag time of seven days so that the decline in radioactivity would be linear throughout the collection period. The specific activity of blood was assigned a value of 100 so that the more closely the fecal radioactivity approached that of blood, the greater was the proportion of dietary P absorbed. With this method no differences were observed in the percentage of P absorbed from dicalcium phosphate or bonemeal. Chicco et al. (1965) also measured absorption in lambs fed a constant daily intake of 700g using a single oral dose of P^{32} with urine and faeces being collected daily and blood periodically. The absorption and retention of P ranked calcium ortho-, sodium meta-, sodium pyro-, calcium meta-, and calcium pyrophosphates respectively. No differences in deposition of P into bone and soft tissue were observed. The low retention of P from calcium pyrophosphate was also reported by Ammerman et al. (1957) in a study with lambs. Witt and Owens (1983) suggested that <u>in vitro</u> P solubility in abomasal fluid may be more indicative as a measure of P availability than solubility in a ruminal buffer, since solubilities in abomasal fluid were higher than in ruminal fluid.

Growth trials utilize a basal diet containing a low level of P supplemented with graded levels of the P source being tested. Hodgson et al. (1948) utilized a growth trial with fattening steers where a control basal diet containing 0.12% P was supplemented with either steamed bone meal or defluorinated super-phosphate to provide dietary levels of up to 0.18% P. They reported no differences in intake and gain between the two P sources. Long et al. (1956) in a study with heifers had a depletion period before the animals were assigned to a basal diet of 0.09% P supplemented to 0.14% P with either dicalcium phosphate or soft phosphate with colloidal clay. The animals fed dicalcium phosphate gained significantly more weight and had higher plasma inorganic P levels as well as percentage of bone ash. Although, soft phosphate contained a relatively high percentage of P it was not well utilized. The authors suggested it may have been due to the high fluoride content (65 ppm). Pope et al. (1958) in a study with steers supplemented a basal diet of 0.2% P with monosodium phosphate at a constant Ca:P ratio to provide levels of 0.3 and 0.4% P. No differences in intake and gain were observed which led to the suggestion that a dietary level of 0.2% P was adequate for yearling steers. A similar recommendation of 0.22% P was proposed by Wise et al. (1958). However, in a later study the supplemented P level was below the recommended level. Wise et al. (1961) in a six-week study with Holstein calves, in which a basal diet of 0.11% P was supplemented to 0.19% P by the addition of either dicalcium phosphate, defluorinated phosphate, Curacao Island phosphate or soft phosphate with colloidal clay, reported no significant differences in weight gain, intake, feed per kg gain, rib ash or rib P content. However; in a subsequent study, when the basal diet was 0.085% P and the experimental period was extended to 14 weeks, calves supplemented with dicalcium phosphate, defluorinated phosphate or Curacao Island phosphate gained significantly more weight than those fed soft phosphate. Feed consumption, ash and ash P content of the ninth rib followed a similar pattern. Although, the longer experimental period appeared to allow significant treatment differences to be manifested, only males were used in the first experiment and females in the second experiment, so it is possible that sex differences may also have contributed to the differences in results. Throughout the literature, it therefore appears that no differences exist in availability of P from bone meal, defluorinated phosphate or dicalcium phosphate.

Balance data are based on total P intake less faecal plus urinary P excreted so that in a balance trial an overall estimate of net retention is given. Ammerman et al. (1957) using the balance technique found no significant differences in P retention from dicalcium phosphate and defluorinated phosphate for yearling steers supplemented at a daily intake P of about 8g with a Ca:P ratio of 1.5:1. Similarly, Arrington et al. (1962), in a study with dairy calves partially depleted of P by feeding a 0.05% P basal diet, observed that supplementation with an inorganic phosphate to provide 0.16% dietary P revealed no significant differences in apparent digestibility of P from dicalcium phosphate and defluorinated phosphate.

Bone breaking strength as a response criteria has been utilized by nutritionists to evaluate the bioavailability of dietary minerals. The majority of studies on the influence of dietary calcium and P on bone strength have been conducted with swine due to the high incidence of leg weaknesses, particularly among breeding stock. The technology has been used to a limited extent with calves. One of the most commonly used test of the mechanical properties of bones is the flexure (bending) test (Crenshaw et al. 1981a and Simkin and Robin 1973). The lack of standardized test procedures however has resulted in a great deal of variation in reported values for bone strength (Crenshaw et al. 1981).

Lott et al. (1980) reported no significant differences in bone breaking strength of fresh or frozen tibia bones from 4 week old broiler chicks. Sedlin (1965) also reported that freezing did not alter the mechanical properties of bone. Sedlin and Hirsch (1966) however, observed that 10-minute exposure of bones to air resulted in increased bone strength. Similarly, Miller et al. (1965) also reported increased bone strength of 5 to 6 week old pig femur dried at 25 ^{O}C for 24 hours. However, wet bones are usually preferable since they more accurately reflect the state in which the bones exist in the animal.

Bayley et al. (1975) and Libal et al. (1969) using corn soybean meal based diets supplemented up to 0.6% P with a constant calcium level, observed no significant increase in the force required to break the femur and metatarsal bones of growing finishing swine. Similarly, Grandhi et al. (1986) observed no significant increase in breaking force, bending moment, ultimate stress and elastic modulus of femur and metacarpal bones of gilts fed 150% of NRC Ca-P levels during the finishing period; although, percent bone ash and calcium were increased which suggested that higher mineralization had occured. Nimmo et al. (1981) however; observed a significant increase in the breaking force of bone from gilts fed similar Ca-P levels throughout the entire growing finishing period. It appeared therefore that levels of dietary Ca-P fed from weaning through to the finishing phase allowed for significant treatment differences. No significant differences in ultimate stress or elastic modulus were reported. Crenshaw et al. (1981 b) conducted a trial with boars, gilts and barrows fed diets containing either 0.4% or 0.8% Ca and P. Mechanical tests were conducted on femur, humerus, metacarpal, metatarsal and third rib bones. When data was pooled across bone and sex; significantly higher bending moment, ultimate stress, modulus of elasticity and percent bone ash were observed for the higher P level. The higher modulus of elasticity indicated that the bone was more rigid and increased mineralization had occurred as confirmed by the higher percentage of bone ash. Brennan and Aherne (1986) also reported significantly higher metacarpal bending moment, and percent bone ash of the femur of boars and gilts fed NAS-NRC (1979) or ARC (1981) recommended Ca-P levels designated low and moderate respectively. Feeding 30% more of the moderate diet significantly increased bone ash but not bending moment.

Dietary Phosphorus levels and Calf Performance

Johnson and McClure (1967) used weanling steers previously depleted of P after which either ammonium polyphosphate or dicalcium phosphate were fed at a rate of 454g animal^{-1} day^{-1} for a 12 week period. No significant differences in feed intake, gain or feed per kg gain were observed between supplements. Although, the form of P in ammonium polyphosphate was mentioned as being the non-ortho form, no confirmation was made as to whether it was meta or pyro forms of phosphorus. However, studies with calcium and sodium metaphosphates have demonstrated that these forms are well-utilized by ruminants (Chicco et al. 1965). Calcium pyrophosphates on the other hand are poorly utilized, possibly due to low solubility and absorption (Ammerman et al. 1957). More recently, Teh et al. (1982) depleted dairy calves for two weeks with a 0.16% P diet and then supplemented the diet with 0.24 or 0.31% P by the addition of either dicalcium phosphate or urea ammonium polyphosphate. Even though increasing dietary P from 0.24 to 0.31% significantly increased feed intake, weight gain, plasma inorganic P, breaking strength of femur and rib bones and the ash content of the tenth rib, no significant differences between dicalcium phosphate or urea ammonium polyphosphate were observed. Thus urea ammonium polyphosphate could be utilized effectively in ruminant diets as a P source as well as a non-protein nitrogen supplement.

Webb et al. (1975) carried out a growth trial with weanling steer calves fed about 0.1% P with or without an initial depletion period. The diets were supplemented to about 0.2% with either defluorinated phosphate or a chemical mixture of 87% monophosphate and 13% dicalcium phosphate. Average daily gain, feed intake and serum inorganic phosphorus levels were significantly lower for animals not supplemented with P. No significant differences in weight gain, feed intake or feed per kg gain were observed between the two sources of phosphorus, suggesting that both were equally available for the ruminant. Langer et al. (1985) also observed no significant differences in average daily gain and feed intake of dairy calves supplemented with monoammonium phosphate or dicalcium phosphate. When no supplement was added, feed intake and average daily gains were significantly lower. In a more recent study, Miller et al. (1987) reported no difference in weight gain, feed intake, feed efficiency, serum inorganic P or bone ash of Holstein calves supplemented with defluorinated phosphate or dicalcium phosphate for diets containing 0.14, 0.20 and 0.32% P. However, the researchers did suggest that the P requirement of young growing dairy calves may need to be revised based on the fact that growth rate, feed consumption, blood inorganic P levels and bone ash tended to increase linearly with increasing dietary P. Teh et al. (1982) also questioned the adequacy of the 0.26% P level for growing heifers and bulls set by NRC (1978). This was based on the observation that calves fed 0.31% P gained an average of 0.84 kg day^{-1} as opposed to 0.62 kg day^{-1} with 0.24% P. Bone ash content was also significantly higher with the 0.31% P which seemed to suggest that this class of animals may have a higher P requirement.

Miller et al. (1987) used a control diet (0.08% P) supplemented to provide 0.14, 0.2 and 0.32% P while Teh et al. (1982) supplemented a 0.16% P basal diet to provide

0.24 and 0.31% P. Both observed increased feed intake, gain, blood inorganic P, bone ash and breaking force of the eighth and ninth ribs. Langer et al. (1985) also observed that increasing the P level from 0.24 to 0.34% significantly increased feed intake, average daily gain, and plasma inorganic P levels. However, at a dietary P level of 0.36% intake and average daily gain were not significantly different from the control. Jackson et al. (1988) in a study with Holstein calves, increased dietary P from 0.26 to 0.34% and observed increased feed intake, average daily gain, bending moment, percentage ash and ash content ($P<0.05$). Plasma inorganic P level increased significantly as dietary P level was increased from 0.26 to 0.41%. Wise et al. (1958) conducted a study with dairy calves depleted of P by a basal diet of 0.09% P which was then supplemented to provide 0.12, 0.18 and 0.30% P. Increased feed intake, gain, percentage of ash in the rib and improved feed efficiency were observed. Based on these results, a second trial was initiated where the dietary P level was increased to 0.14, 0.22, 0.30 and 0.38%. Increased feed intake, weight gain, ash in rib and improved feed per kg gain were observed up to a dietary P level of 0.30%. These findings are consistent with the study by Langer et al. (1985) and also point to the fact that the minimum P requirement for dairy calves needs to be revised. The NRC (1978) P requirement for growing dairy heifers and bulls was 0.26% P and has now been revised to 0.31% P (NRC, 1988).

Rumen Phytase Activity

Studies by Raun et al. (1956) using an artificial rumen technique, whereby a washed suspension of rumen microorganisms initially depleted of P was incubated at 39 °C for 24-72 h with 1-32 mg of calcium phytate per 20 ml of medium, were able to show that rumen microorganisms possess the enzyme phytase and thus have the ability to degrade phytate. The amount of inorganic P released from calcium phytate increased from 0.27 mg per 20 ml of medium to 1.58 mg per 20 ml of medium with the higher levels of calcium phytate. The increase in inorganic P after incubation represented phytate P hydrolysed by the phytase produced by the microorganisms. The enzyme phytase however has also been reported to be present in canola seeds (Kim and Eskin 1987). The enzyme has been reported in soybeans, wheat, corn seeds and fababeans (Chang 1967, Latta et al. 1980, Sartirana et al. 1967 and Singh et al. 1979). The hydrolysis of phytate is catalyzed by the enzyme phytase (myoinositol hexaphosphate phosphohydrolase E.C. 3.1 3.8) to inositol and free inorganic phosphate. Eskin and Wiebe (1983) reported an average reduction in percent phytate content of 75% with increased wheat phytase activity measured as μ g Pi/mg enzyme / 30 minutes.

Canola Meal in Ruminant Diets

Clark and Bezeau, cited in Whiting (1965) reported that the inclusion of 6% rapeseed meal (RSM) in place of linseed meal in the diet of young Holstein calves had no effect on feed intake or growth rate. Ingalls and Seale (1971) substituted RSM for soybean meal (SBM) at levels of 6.8 and 13.7% in barley-based calf diets offered free choice. No significant differences in feed intake, weight gain or feed efficiency were reported. The inclusion of either 14% SBM or 20% RSM in diets fed to Holstein calves from 8 to 22 weeks of age resulted in no significant differences in feed intake, weight gain or feed efficiency (Sharma and Ingalls 1973). Stake et al. (1972) in a study with Holstein calves from birth to 8 weeks of age, fed isonitrogenous calf starter diets containing RSM, SBM or sunflower meal. When RSM made up 26% of the diet, dry matter consumption was significantly lower than for SBM or sunflower meal. No significant differences in average daily gain or feed efficiency were observed from birth to 14 weeks. Ingalls and Waldern (1972) reported that a diet containing 30% RSM reduced weight gain when compared to 20% RSM in the diet. When a diet containing 24% RSM was offered free choice to Holstein calves from birth to 12 weeks of age, significantly lower feed intake, weight gain and feed efficiency were observed than, for calves fed a SBM diet (Schingoethe et al. 1974). When a low glucosinolate cultivar (c.v. Bronowski) was fed at a dietary level of 20% no significant differences in weight gain or feed efficiency for SBM and the low glucosinolate RSM were observed.

The limited use of RSM in calf diets has been primarily due to unpalatability and goitrogens present in the seed. The reduction in the glucosinolate level in the seed through breeding has resulted in higher dietary level incorporation of canola meal (CM) in calf diets.

In a study by Burton (1983) calves were fed milk replacer in which 15% of the milk protein was replaced with canola or soybean protein. Calves fed canola protein had significantly higher average daily gain and improved feed efficiency, although this wasn't significant. Sharma et al. (1980) conducted a digestibility study with 18-20 week old bull calves in which 50% of a corn-oat based basal diet was mixed with an equal amount of SBM or canola meal. The diets were offered free choice and they observed significantly higher apparent dry matter and crude protein digestibility with the SBM than with the canola meal. This may have been due to the rapeseed hulls that are less digestible than SBM hulls (Kendall 1988, Rae and Smithard 1985). Claypool et al. (1985) compared CM with SBM and cottonseed meal (CSM) in barley-corn based calf starter diets offered free choice during a preweaning period and fed at 2.27 kg per head daily at the post-weaning period. They reported no significant differences in average daily gain, starter or milk consumption or packed blood cell volumes. In a study with dairy calves Tower CM was partially or completely substituted for SBM at dietary levels of 8.3 and 17.2% respectively in isonitrogenous calf starter diets offered free choice to 12 weeks of age (Wheeler et al. 1980). No significant differences in feed intake or average daily gain among diets were reported. Similarly, CM has been used successfully in beef steer diets (Bush et al. 1978).

Milk production and milk composition of cows in early lactation fed CM at levels up to 25% in the diet were not significantly different from those fed SBM (Brockman et al. 1983, Laarveld and Christensen 1976, Laarveld et al. 1981, Papas et al. 1978, Sanchez and Claypool 1983 and Sharma et al. 1977). A trend towards higher milk production in cows fed CM has been reported (Laarveld and Christensen 1976, Papas et al. 1978 and Sanchez and Claypool 1983). However, Fisher and Walsh (1976) reported a decline in milk production when CM was incorporated into the diet at a level more than 11%. This may have been due to the high level of oil in the sample of meal used.

Protein degradation in the rumen and the Mobile Nylon Bag Technique

Nylon bags incubated in the rumen for varying lengths of time (Bailey and Hironaka 1970, Barrio et al. 1986, Crawford et al. 1978, Mathers et al. 1977, Mehrez and Orskov 1977, Mohammed and Smith 1977 and Orskov and McDonald 1979) have been used to give rapid estimates of protein degradation in the rumen. Nocek (1985) feeding a 50:50 rhoughage: concentrate total mixed diet reported that dry matter disappearance from SBM using polyester bags compared well with in vivo estimates when pore sizes of 40 - 120 μm were used.

Weakley et al. (1983) reported lower dry matter disappearance from dacron bags with a pore size of 5 μm compared with that from 52 μm bags. Deacon et al. (1988) fed cannulated cows a total mixed diet of a 50:50 rhoughage: concentrate ratio using nylon bags having a pore size of 48 μm they reported no difference in dry matter disappearance for untreated CM and extruded CM. Nocek (1988) recently recommended that bag porosity of 40 - 60μm was adequate in minimising influx into and efflux from the bags. The fineness of grind of the feed samples will also affect disappearance of soluble dry matter. Nocek (1985) reported no effect on dry matter digestion constants for samples ground to pass through a 1, 2 and 5mm screen. As samples weight: surface area ratio increased (2.5, 12.6, 25.3 and 37.9 mg/cm^2) the disappearance of dry matter decreased for SBM.

Sauer et al. (1983) developed a modified nylon bag technique for pigs whereby samples after pre-digestion with pepsin-HCl were then inserted into the small intestine via a duodenal cannula. Kirkpatrick and Kennelly (1984) attempted to modify the technique for use by ruminants by placing nylon bags previously incubated in the rumen for 15 hours, in pepsin-HCl for 3 h and then inserting them into the small intestine via duodenal cannulae. They obtained mean crude protein digestibility of 68.9% with the modified nylon bag as compared to 74.5% with the conventional fecal collection studies, for diets varying in crude protein levels from 16% to 19%. Mean dry matter digestibility was 50.3 for the nylon bag technique and 66% for the conventional method. Kendall (1988) reported dry matter and protein digestibility of 38.1 and 68% respectively at 16 h of rumen fermentation for canola meal. For SBM dry matter and protein digestibility was 77.3 and 88.4% respectively. Although, there may be limitations, use of the mobile nylon bag technique to study nutrient disappearance in the lower GI tract appears promising.

Materials and Methods

Growth Trial

Forty-two Holstein bull calves were placed in individual pens bedded with shavings and were fed whole milk for 4 weeks. The calves were fed 2 kg of milk twice per day through 4 weeks of age and then 2 kg of milk once per day supplemented with a general calf starter diet (Table 1) fed free choice until 5 weeks of age. At five weeks of age all calves received a 50:50 mixture of general calf starter and experimental diets assigned at random and fed *ad libitum*. All calves received 1 ml of an intramuscular injection of Poten A.D.E.[1] (containing Vitamin A, 500,000 I.U.; Vitamin D_3, 75,000 I.U.; Vitamin E 50 I.U. in 100 ml) at 4 weeks. The seven dietary treatments (Table 2) starting at 6 weeks of age consisted of the basal diet (0.25% P) as the control and the control diet supplemented with phosphorus (by replacing corn starch) from canola meal or inorganic phosphorus to provide levels of 0.32, 0.36 and 0.40% P. Additional fat was added to the canola meal diets to result in isocaloric diets. The calves were individually fed their respective diets *ad libitum* in pellet form for 10 weeks with the amount of feed offered being recorded daily and weigh backs taken on day 7 of each week. Water was available free choice. The calves were weighed at the start of the experiment and then every 2 weeks thereafter. Six

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[1] Rogar/STB Inc. London, Ontario N6A 4C6.

TABLE 1. Ingredient composition of pre-trial calf starter diet.

Ingredients	Composition (% as fed)
Hay, ground	16.0
Barley, rolled coarse	49.0
Oats, rolled coarse	15.8
Canola meal	9.7
Molasses	3.0
Tallow	3.0
Biophos[1] 21% P 16.5% Ca	1.5
Urea 45% N	0.8
Mineral mix[2]	0.8
Vitamin mix[3]	0.4
	100.0

[1] Approximately 2/3 monocalcium phosphate and 1/3 dicalcium phosphate. Pitman-Moore 421 East Hawley St., Mundelein, Illinois 60060.

[2] Contributed the following per kg of diet: Cu, 8.8 mg; Se, 0.17 mg; Zn, 32 mg; Mn, 27.2 mg; Mg, 432 mg; K, 984 mg; Na, 984 mg.

[3] Vitamin mix contributed the following per kg of diet: Vitamin A, 7000 I.U.; Vitamin D_3 I.U.; Vitamin E, 120 I.U.

TABLE 2. Ingredient composition % of experimental diets fed to calves from six weeks to 16 weeks of age.

	Dietary Treatments						
	0.25% P	0.32% P		0.36% P		0.40% P	
	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos
Alfalfa dehydrated pellets 17% CP	6.0	6.0	6.0	6.0	6.0	6.0	6.0
Beet pulp	23.0	23.0	23.0	23.0	23.0	23.0	23.0
Brewers dried grain 28% CP	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Corn Starch	30.6	26.0	30.0	21.0	30.4	15.0	30.2
Corn (ground)	15.7	15.7	15.7	15.7	15.7	15.7	15.7
Fat (tallow)	-	0.6	-	0.6	-	1.71	-
Molasses cane dried	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Soybean meal 49% CP	11.7	11.7	11.7	11.7	11.7	11.7	11.7
Urea 45% N	0.44	-	0.44	-	0.44	-	0.44
$CaCO_3$ Limestone 38% Ca	0.82	0.66	0.71	0.67	0.60	0.57	0.47
Biophos 25% P 16.5% Ca	-	-	0.26	-	0.53	-	0.81
Canola meal	-	5.0	-	10.0	-	15.0	-
Trace mineral salt[1]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Contributed the following per kg of diet: Cu, 5.5mg; Se, 0.11mg; Zn, 20mg; Mg, 2.7×10^5 mg Na, 1.14×10^5 mg.

representative samples of each diet were collected using a grain sampling probe, twice throughout the experiment, composited and then ground in a Wiley mill with a 1.0 mm mesh screen before analysis (Table 3).

Blood samples were taken from the jugular vein of each calf at the start of the experiment and every 2 weeks thereafter. 10 ml samples were collected and placed in two 5 cc vacutainers (Becton Dickinson, U.S.A.) and put on ice until centrifuged. At the end of the 70-day treatment period, calves were shipped to a local abbatoir where they were slaughtered and the eighth and ninth rib bones removed and placed in a cooler until shipment back to the University. The bone samples were then cleaned of adhering tissue and placed in individual plastic bags and frozen at -20 °C until further analysis.

<u>Measurement of phosphorus disappearance in the rumen and lower gastrointestinal tract</u>

Two rumen cannulated Holstein steers were fed <u>ad libitum</u> a diet formulated to meet the energy and protein requirements of high producing dairy cows (Table 4) to provide 19% crude protein and 14% crude fibre. The feed samples consisted of soybean meal from a processor in Altona, Manitoba as the reference standard and five different commercial samples of canola meal (Table 5).

TABLE 3. Determined chemical analysis and calculated energy and degradable protein levels of experimental diets on a dry matter basis.

Item	Dietary Treatment						
	0.25% P	0.32% P		0.36% P		0.40% P	
	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos
Dry matter, %	92.3	91.9	92.4	93.2	92.7	93.6	93.0
Crude protein, %	14.3	15.8	14.1	16.7	14.7	17.9	15.1
Crude fat, %	1.4	1.2	1.3	2.1	1.1	3.2	1.3
NDF, %	22.9	21.8	21,2	20.8	20.9	22.7	19.1
ADF, %	9.5	11.5	11.0	11.1	10.0	12.7	9.6
Phosphorus, %	0.25	0.32	0.32	0.36	0.36	0.40	0.40
Calcium, %	0.61	0.59	0.62	0.73	0.61	0.60	0.63
Magnesium, %	0.15	0.20	0.17	0.22	0.19	0.25	0.15
Ash, %	6.5	6.6	7.1	7.0	7.3	7.9	6.7
Copper, ppm	13.1	12.2	11.8	16.0	11.0	11.3	11.1
Zinc, ppm	49.3	46.6	53.5	53.0	52.7	61.6	42.9
Iron, ppm	444.8	389.2	391.1	384.4	538.0	349.6	511.0
Manganese, ppm	39.2	37.1	41.7	47.2	50.7	44.7	39.7
NEm, M cal/kg DM	1.96	1.92	1.95	1.89	1.95	1.89	1.94
NEg, M cal/kg DM	1.31	1.34	1.30	1.29	1.31	1.31	1.30
Undegradable intake protein (%)	5.9	6.6	5.7	6.3	6.0	6.6	6.1

TABLE 4. Ingredient composition of the diet for steers used in the rumen incubation and lower gastrointestinal tract digestibility studies of five canola meal samples and soybean meal.

Ingredient	Run 1 (16h)	Run 2 (12h)
Alfalfa hay	36	-
Brome hay	-	35.2
Canola meal	11.4	20.8
Barley	51.7	43.1
Urea	0.25	0.25
Biophos	0.32	-
$CaCO_3$	-	0.29
Trace mineralized[1] salt	0.35	0.38

[1]The salt-trace mineral premix provided per kg diet: copper, 6.6 mg; zinc, 24.1 manganese, 20.4 mg; selenium, 0.5 mg; magnesium, 327.6 mg; vitamin A, 5250 IU; vitamin D_3, 450 IU; vitamin E, 6 IU.

TABLE 5. The commercial sources of canola meal and SBM used in the rumen incubation and lower gastrointestinal tract digestibility studies.

A. CSP Foods canola meal (CSP-CM) (38.05% CP, 1.04% P).

B. NARP Processors canola meal (NARP-CM) (Northern Alberta) (38.84% CP, 1.10% P).

C. Alberta Food Products canola meal (ALB-CM) (38.34% CP, 1.12% P).

D. Canbro Foods canola meal (CF-CM) (39.8% CP, 1.12% P).

E. United Oilseeds Products canola meal (UOP-CM) (37.66% CP, 1.04% P).

F. CSP Foods soybean meal (SBM) (45.71% CP, 0.75% P).

Nylon cloth[2] with a mean pore size of 50μm was used for the in situ bag preparation. The bags were 3.5 X 5.5 cm in size. Approximately 0.5000 ± 0.0001g of feed sample as recieved from the processor was introduced into each bag. The bags were mixed randomly and placed in the legs of an old pair of panty hose using marbles as weights. About 21cm of rope (enough line for free movement) was tied to the panty hose, placed in the rumen, secured and the samples incubated. Four samples of each feedstuff were incubated in the rumen for 12h and 16h. The 12 and 16h incubations took place on different days. Four blank bags containing a known weight of nylon cloth were used to correct for efflux or influx into the bag. After removal from the rumen, bags were washed with tap water until the rinse fluid was clear. The bags were then drained, oven dried at 60°C for 48h, cooled in a dessicator and weighed. Two bags for the rumen results were separated out and P determined as described above. P loss during rumen incubation was calculated by subtracting the corrected gms of P left after incubation from the gms of P present before incubation in the rumen.

Total P loss from the rumen = (feed sample weight X %P)-[(rumen incubated sample weight X %P) - (Blank sample weight X %P)]. The average value for the gms of P for the blanks was 0.0003 gms or 1.6% of the remaining P. The bags

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[2] Felco industries, Concord, Ontario, Canada. L4K 2H3.

from the 12h rumen incubation were placed in 0.01N HCl; pepsin $1gl^{-1}$ and incubated at 39°C for 3h to simulate digestion in the abomasum. The 16h samples did not go through the pepsin-HCl digestion. Two bags from each rumen incubation for each sample were inserted into the small intestine via a duodenal cannula. Bags for incubation in the small intestine were placed on ice (about 4°C) and inserted into duodenal canulae at the rate of 2 bags h^{-1} $animal^{-1}$, and retrieved in the faeces 16-20h later. The faeces were gently hosed through a sieve box and the bags recovered. The nylon bags were then dried with paper towels, oven dried at 60°C for 48h, cooled in a dessicator, weighed and then analyzed for P according to the procedure of A.O.A.C. (1984) method no. 7.123. The total P loss from the lower tract was calculated by subtracting the corrected gms of P left in faeces from the corrected gms of P left after rumen incubation. The P lost during pepsin HCl digestion was calculated by subtracting the corrected gms of P left after pepsin-HCl from the corrected gms of P left in the rumen after incubation.

Total P loss from the lower tract =

[(rumen sample weight X %P) - (rumen blank sample weight X blank %P)] -

[(faecal sample weight X%P) -(faecal blank sample weight X faecal blank %P)]

The average value for the gms of P for the faecal blanks was 0.0004 gms for 16h rumen incubation and 0.00006 gms for 12h rumen incubation followed by pepsin HCl digestion. The apparent P digestibility was calculated as:

$$\frac{\text{(gms of P present before rumen incubation - corrected gms of P left in faeces)}}{\text{(gms of P present before rumen incubation)}}$$

Analytical Procedures

Feed samples were dry ashed in a "Cold ashing oven" at 550°C for 12 hours. The resulting ash was diluted with a mixture of 5N Hcl and 1% nitric acid (v/v) and analyzed in the presence of 5% Lanthanum reagent for Ca, Mg, Fe, Zn, Cu and Mn by spectrophotometry (aa/ae spectrophotometer Model 551 Instrumentation Laboratory, Inc.) and for phosphorus by colorimetry (A.O.A.C., 1984 method no. 7.123).

The rib samples were thawed to room temperature in sealed plastic bags before being subjected to the flexure test using an Instron Universal Testing Machine.[3] The machine was set up to have an up velocity of 600mm min^{-1} and a down velocity of 5mm min^{-1}. The force in Newtons was set in low range (0-1000 N) with the deflection being read in mm. The specified delay time between measurements was 1 second. The rib was tested using a flexure test (bending

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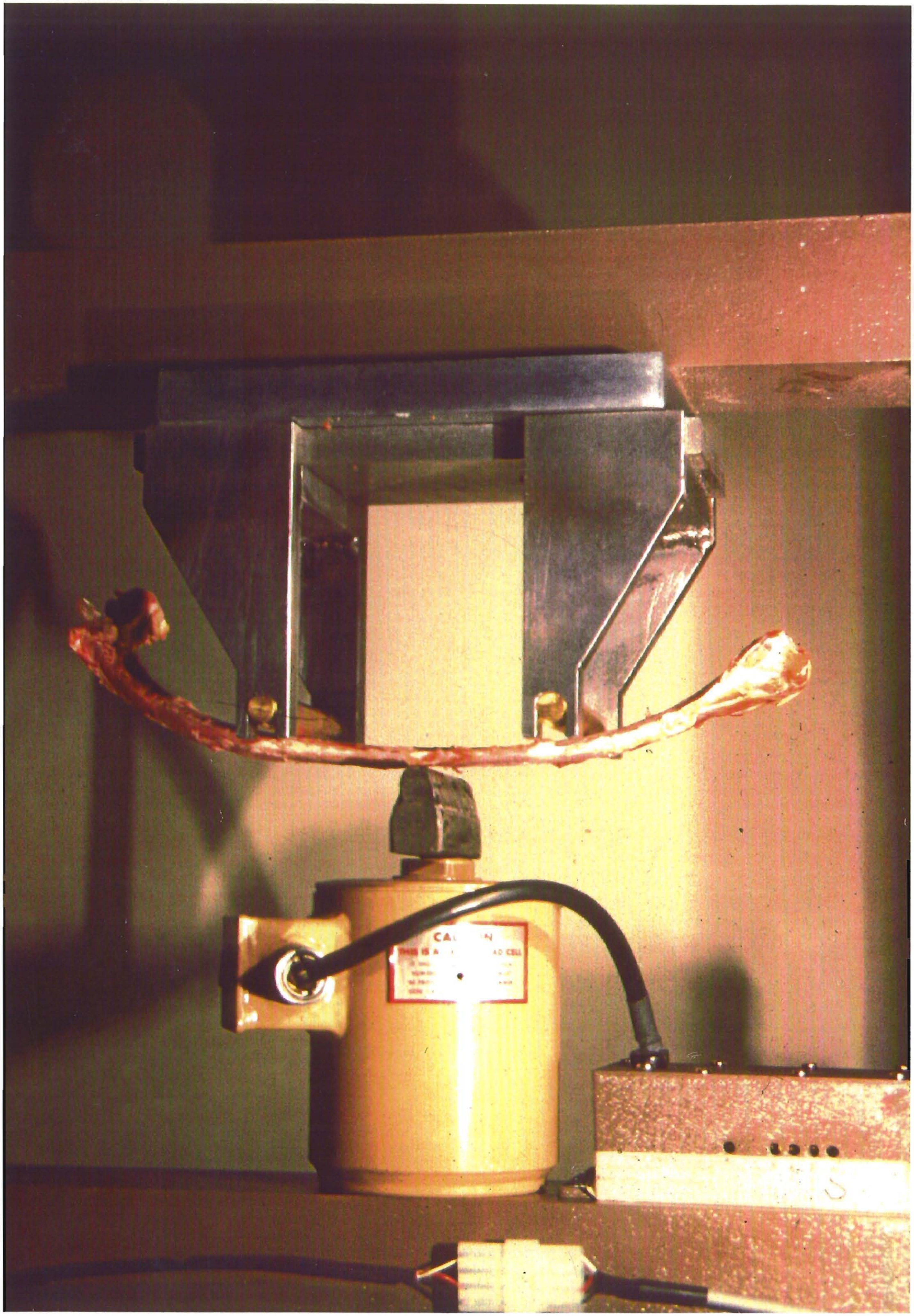
[3] Model ET 1100 RS2, John Chatillon & Sons, New York, N.Y., U.S.A.

test) at a support distance of 100mm (Figure 1). The force was applied at the midshaft at a constant speed of 5mm min^{-1}. A special chisel adaptor head constructed by the University of Manitoba Engineering Department was forced upon the centre of the rib. The force required to break the rib resistance increased, peaked and then decreased and was automatically recorded on a Tandy 1000 computer. The program used was a Bios ROM version 01.01.00 Copyright 1984, 1985 Tandy Corp. and Phoenix Compatibility Corp. The Tandy Version 02.11.22 Microsoft MS-DOS Version 2.11 was loaded by typing in **Basica a test/c: 9000** command. The test was stopped when the force peaked and then started to decline, thus indicating that the ultimate breaking force had been reached. Measurements were made at the point of loading (midshaft) to determine the outside rib diameter and thickness. At the end of the mechanical tests, 3cm cross-sections were taken from the rib at the point of applied force for determination of bone ash, calcium and phosphorus. The bone samples were dried in a forced air oven at 70 ^{o}C for 5 days after which they were broken, then extracted in a Soxlet apparatus with anhydrous ethyl ether for 5h for removal of lipid, redried and ashed in a cold ashing oven at 550 ^{o}C for 12 hours. The ash was placed in 25 X 150mm Borosilicate culture tubes and 20ml of a mixture of 5N HCl in 1% HNO_3 (v/v) were added. The samples were allowed to degas for five minutes after which they were

Figure 1: The Instron Universal Testing machine with a representative rib sample in testing position.



capped tightly. The tubes were then placed in an ultrasonic water bath at 65^{o}C for 60 minutes. After cooling the tubes were mixed by inversion four times and allowed to stand overnight. Calcium was determined by atomic absorption spectrophotometry on an aa/ae Spectrophotometer Model 551 Instrumentation Laboratory Inc. by the procedure of Thompson and Blanchflower (1971). Phosphorus determination was by colorimetry with a Bausch and Lamb Spectronic 20 (Fisher Scientific Ltd.) as described by the Association of Official Analytical Chemists (AOAC) (1984 method no. 7.123).

Blood samples were centrifuged at 2000 r.p.m. for 20 minutes in an Adams Dynac centrifuge (TM Clay - Adams, Inc.). The plasma layer was withdrawn using a pipette and stored frozen (-20^{o}C) in 5ml borosilicate glass vials until ready for analysis. All the glassware that was used for analysis was washed and rinsed three times in distilled deionized water. It was then soaked overnight in 10% HNO_3 (v/v) rinsed six times with distilled water and oven dried at 60^{o}C.

After wet digestion using a mixture of 4 parts nitric acid and 1 part perchloric acid (Thompson and Blanchflower, 1971) blood samples were diluted with 5% HCl and analyzed for calcium by atomic absorption spectrophotometry and for phosphorus as described above.

Feed Analysis

The crude protein content of feed samples was determined according to the method number 7.015 of the Association of Official Analytical Chemists (A.O.A.C., 1984). Neutral detergent fiber of the feed samples was determined according to the procedure of Goering and Van Soest (1970). Acid detergent fibre of feed samples was determined according to A.O.A.C., (1984) method no. 7.074. Crude fat content of the feed samples was determined by weighing 2 gm of previously dried sample into a Goldfisch extraction apparatus (A.O.A.C. 1984, method no. 7.060). The lipids were extracted with anhydrous ethyl ether for 4h in a Soxlet apparatus. The percentage fat on dry matter basis was calculated as:

$$\frac{\text{Weight of fat in beaker}}{\text{dry weight of sample}}$$

The equipment used for the feed analysis were from Labcanco corporation.[4]

Statistical Analysis

Statistical analysis of the data was based on a split plot design where repeated observations were made of animals in two periods of growth. The experimental treatments used two sources of P, each at three different concentrations in calf diets and a control diet (7

[4] Labconco Corporation, 811 Prospect, Kansas City, Mo. U.S.A. 64132

treatments in total). The general linear models procedure of the Statistical Analysis System Inc. (1982) was used. The Statistical model used for analyzing the effect of dietary P on performance and bone characteristics was:

$Y_{ijkl} = \mu + T_i + A_j(T_i) + W_k + (TW)_{ik} + e_{ijkl}$

Y = dependent variable

μ = overall mean

T_i = effect of the i^{th} dietary treatment

$A_j(T_i)$ = effect of the j^{th} animal within i^{th} treatment

W_k = effect of the K^{th} period (period 1 = week 0 to 4, period 2 = week 4 to 10)

$(TW)_{ik}$ = The interaction of the i^{th} treatment within the K^{th} period

e_{ijkl} = error term

Type III sum of squares with animal within treatment as the error term was used to test for significant treatment effects.

The in situ data was analyzed as a completely randomized design using one way analysis of variance.

Duncans multiple range test ($p < 0.05$) (Snedecor and Cochran, 1980) was used to determine significant differences among main treatment effects.

Results and Discussion

Growth trial

Dry matter feed intake over both growth periods was not significantly ($p > 0.05$) increased when diets were supplemented with dietary P (Table 6 ; Fig. 2, 3, 4; appendix Table 1). This is in agreement with the results of Wise et al. (1958) who observed no significant differences in feed intake of calves fed 0.22, 0.3 or 0.38% P. Jackson et al. (1988) however, reported significant increases in feed intake when dietary P was increased from 0.24% to 0.34%. A level of 0.41% resulted in no significant improvement. Similarly, Teh et al. (1982) and Langer et al. (1985) observed significantly higher feed consumption when dietary P was increased from 0.24% to 0.30%. When dietary P was supplied to 0.36% no further improvement occured (Langer et al. 1985). Even though in the present study, feed consumption was not significantly increased there was a trend ($P = 0.1$) towards higher consumption by calves fed the CM supplemented diets as the P level was increased from 0.32 to 0.36% (Table 6, Fig. 3, 4). Figures 2, 3 and 4 represent feed consumption for calves supplemented with phosphorus from CM or Biophos. It appeared that calves supplemented with CM consumed more than those on the control or Biophos treatments. At ten weeks there appeared to be higher DM intake of CM supplemented diets over the control with an intermediate level for the Biophos

TABLE 6. Effect of dietary P level on performance of male Holstein calves.[1]

	Dietary Treatment							
	0.25% P	0.32% P		0.36% P		0.40% P		
Parameter	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos	± S.E.[2]
Dry matter intake (g)								
0-5 weeks	55.5 (2.9)[3]	54.1	58.8	56.8	47.5	60.3	51.0	2.6
5-10 weeks	77.7 (2.9)	79.2	81.6	90.5	81.4	91.3	77.4	2.6
0-10 weeks	133.2	133.3	140.4	147.3	128.9	151.6	128.4	
Weight gain (kg)								
0-4 weeks	17.8 (2.2)	18.2	20.7	19.0	15.7	22.1	14.5	2.0
4-10 weeks	26.4 (2.2)	29.7	28.2	31.7	27.8	31.5	27.5	2.0
0-10 weeks	44.2	47.9	48.9	50.7	43.5	53.6	41.0	
Feed:gain								
0-4 weeks	2.87 (0.27)	2.61	2.40	2.68	2.78	2.37	3.19	0.25
0-10 weeks	3.52 (0.27)	3.22	3.37	3.27	3.40	3.37	3.52	0.25

1 Least squares means.

2 Standard error of the mean with six animals per treatment except for the control, which had five animals.

3 Numbers in parenthesis indicate the standard error for the control.

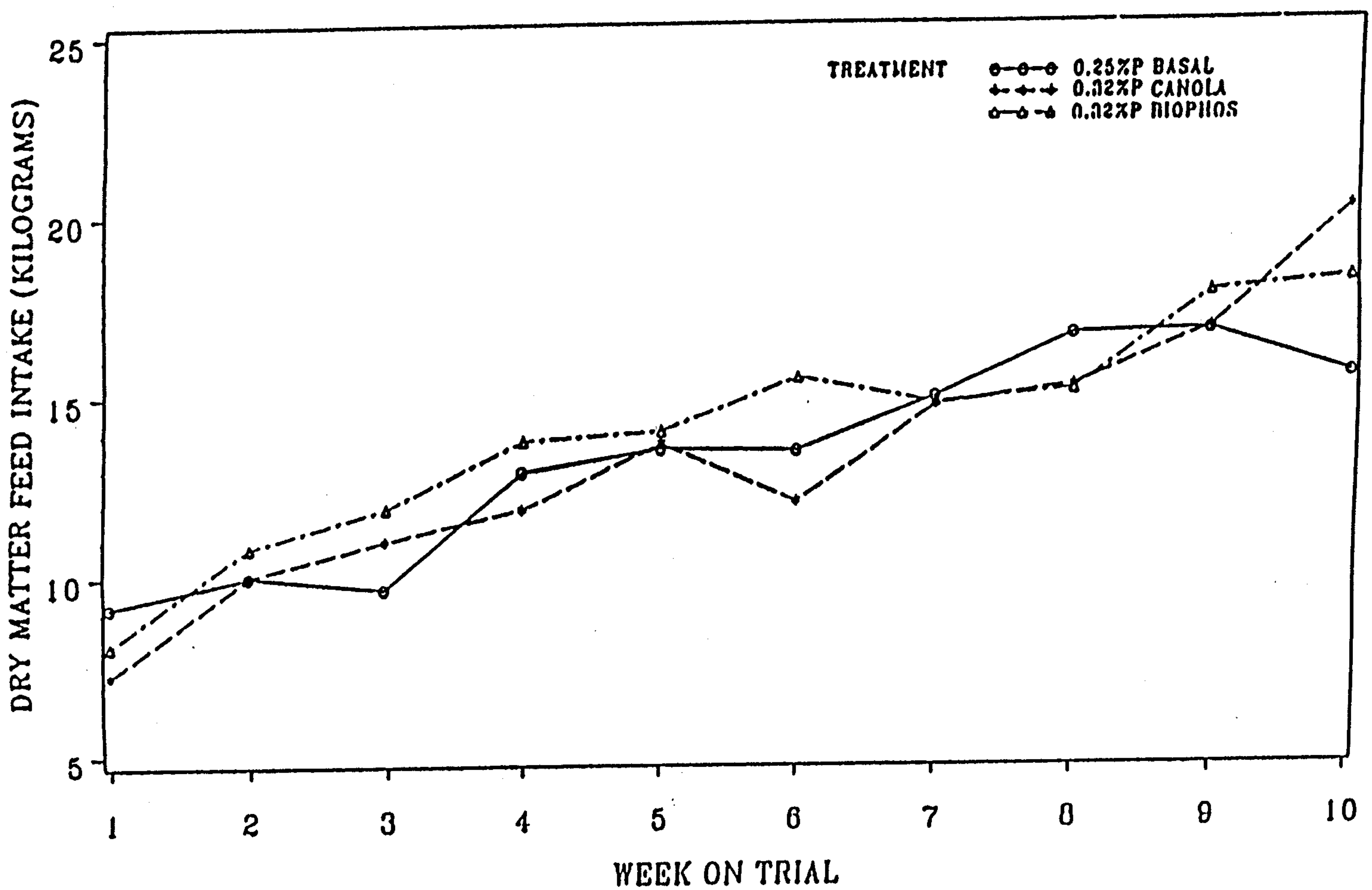


Figure 2. The total dry matter feed intake of calves fed 0.32% phosphorus from two sources.

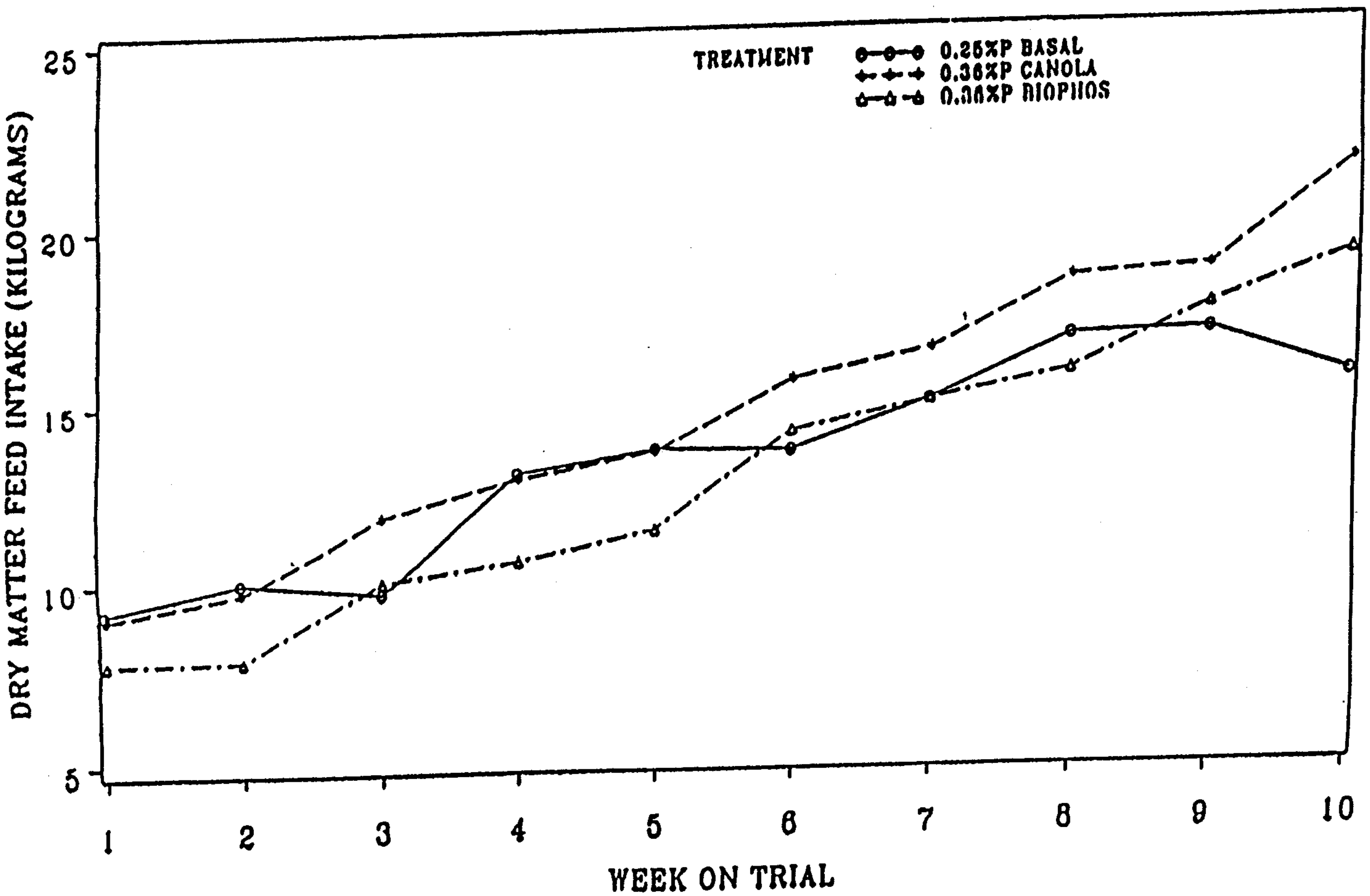


Figure 3. The total dry matter feed intake of calves fed 0.36% phosphorus from two sources.

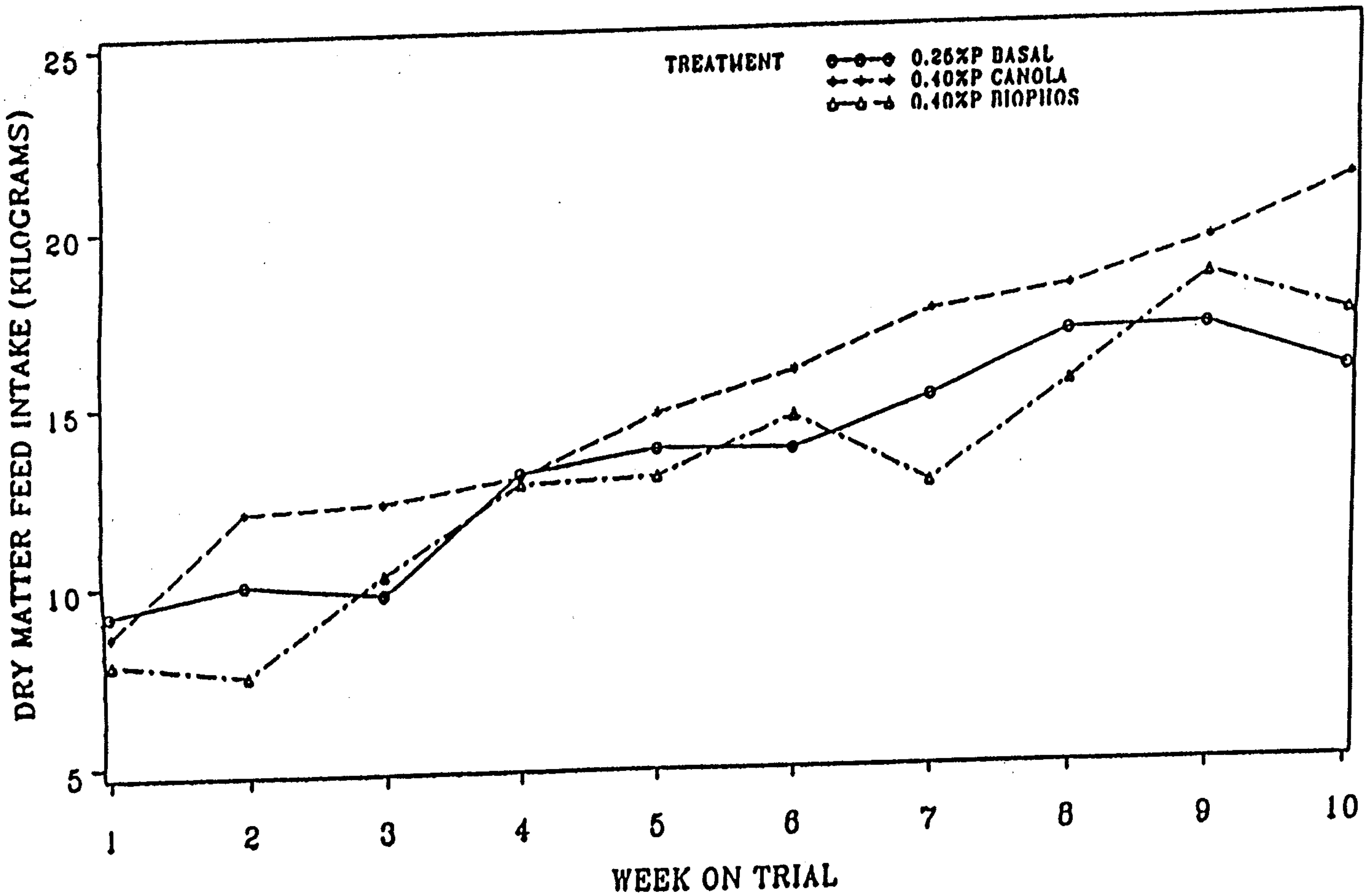


Figure 4. The total dry matter feed intake of calves fed 0.40% phosphorus from two sources.

supplemented diets (Fig. 3, 4). The daily dry matter intakes over the 4-10 week period (Table 7) were 83 to 91% of that suggested for large breed calves averaging 96 kg with the rate of gain obtained in this experiment (NAS-NRC 1988). There were no significant ($p > 0.05$) differences in weight gain due to treatment (Table 6; Fig. 5, 6, 7), although, there tended to be an increase in gain with increasing dietary P level among the CM supplemented diets (Fig. 6, 7). This is in contrast to the results of Teh et al. (1982) who reported a significant improvement in total gain from 34.7 kg to 46 kg over 8 weeks when dietary P was increased from 0.24% to 0.31%. Langer et al. (1985) also reported significantly higher average daily gain (ADG) from 0.84 kg/day to 0.94 kg/day when dietary P level was increased from 0.24 to 0.30. More recently, Jackson et al. (1988) reported significantly higher ADG from 0.84 to 0.94 kg/day when dietary P was increased from 0.26 to 0.34%. Failure for the treatment differences to be significant may be due to the high variability (Table 8) in weight gain among animals and a limited number of animals. Field and Woolliams (1984) using chimaera-derived sheep to minimize individual variation, were able to show that among four sets of triplets the efficiency of P absorption varied from as low as 62% to as high as 84%. The results of this study are in agreement with those of Pope et al. (1958) who also showed no differences in ADG when dietary P was increased

TABLE 7. The actual feed intake and gain of calves averaging a body weight of 96 kg[1].

	Dietary Treatments						
	0.25% P	0.32% P		0.36% P		0.40% P	
	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos
Feed intake kg/day	2.69	2.72	2.82	2.99	2.65	3.02	2.65
Total crude protein g							
Consumed	355	394	367	466	360	507	371
Required[2]	390	478	456	530	435	532	410
Consumed/required (%)	91	82	80	88	83	95	90
Undegradable intake protein g							
Consumed	146	165	149	176	147	187	150
Required	362	442	424	491	402	495	379
Consumed/required (%)	40	37	35	36	36	38	40
Degradable intake protein g							
Consumed	209	229	218	290	213	320	221
Required	72	88	85	98	80	99	76
Consumed/required (%)	290	260	256	296	266	323	291
Calcium g/day							
Consumed	15.1	14.7	16.2	20.3	15.0	17.0	15.5
Phosphorus g/day							
Consumed	6.2	8.0	8.3	10.0	8.8	11.3	9.8
Daily gain kg							
Expected[3]	0.83	0.85	0.92	1.01	0.82	1.07	0.81
Actual[4]	0.81	0.99	0.95	1.01	0.90	1.11	0.85
Actual/expected (%)	98	116	103	109	110	104	105

1 The average liveweight of calves from 4-10 weeks on test
2 Requirement for 96 kg calves from NRC 1989 Table 6-2
3 Based on energy consumed using NEm and NEg calculations
4 Average daily gain from 4 to 10 weeks on test

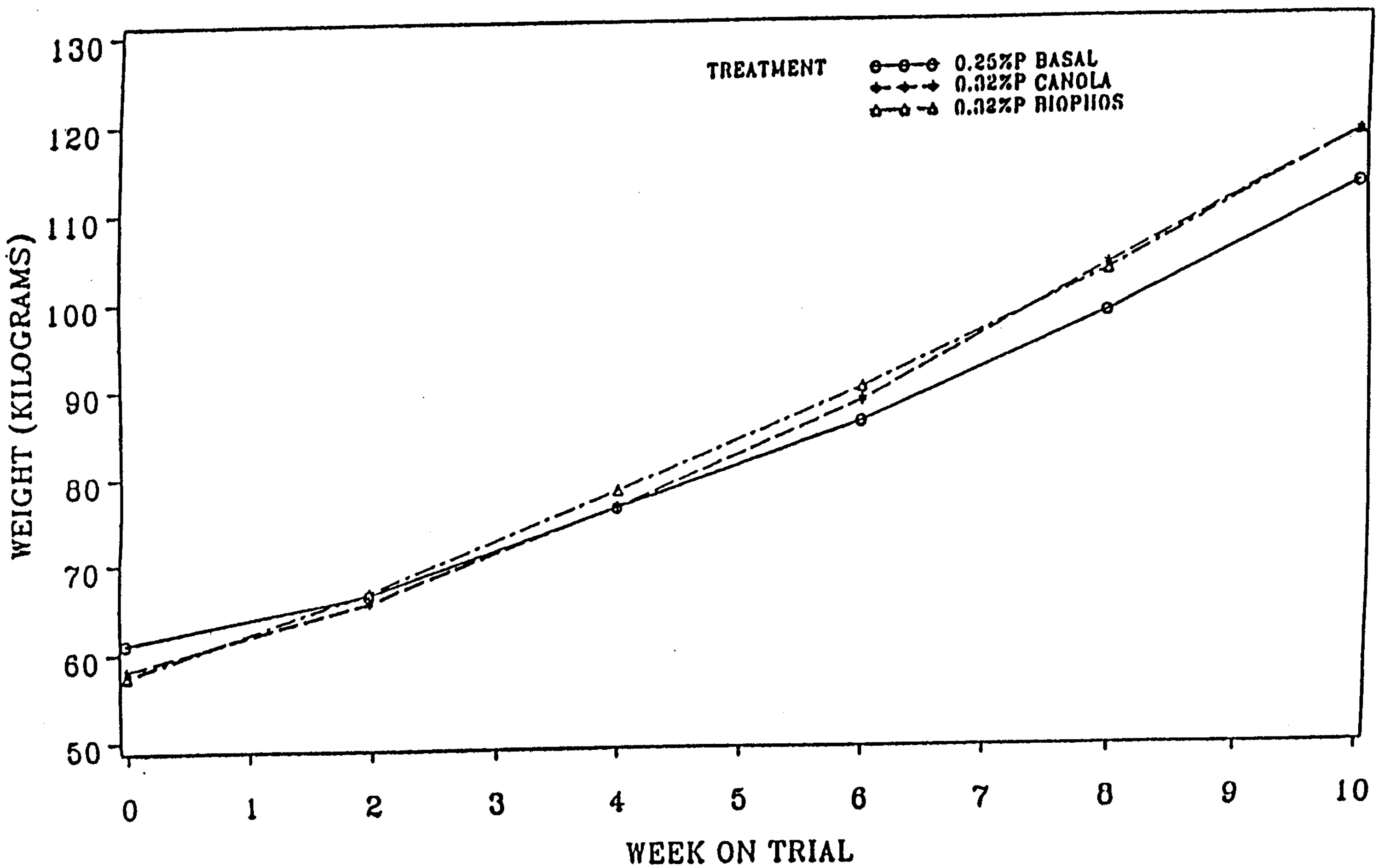


Figure 5. The liveweight body change of calves fed 0.32% phosphorus from two sources.

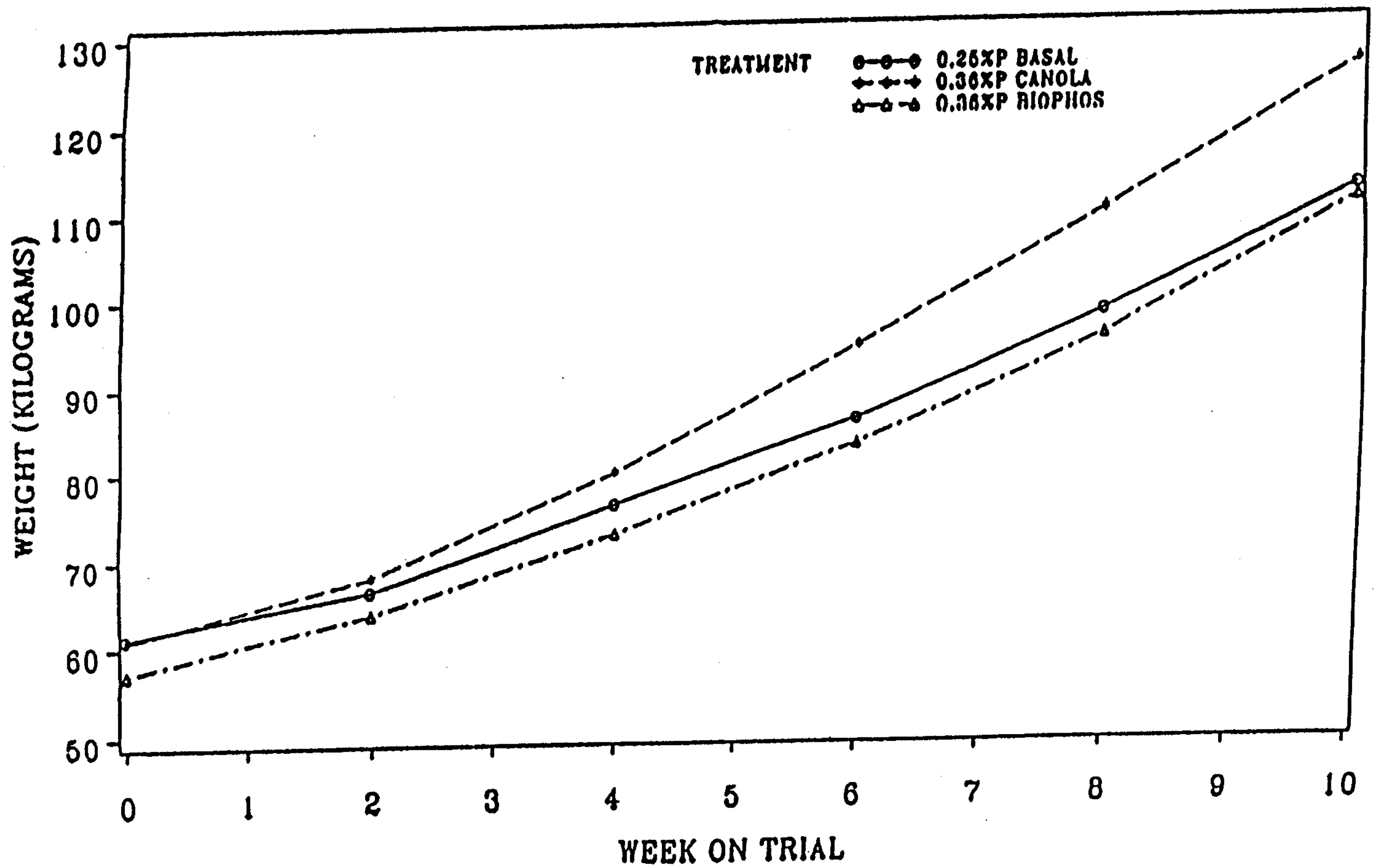


Figure 6. The liveweight body change of calves fed 0.36% phosphorus from two sources.

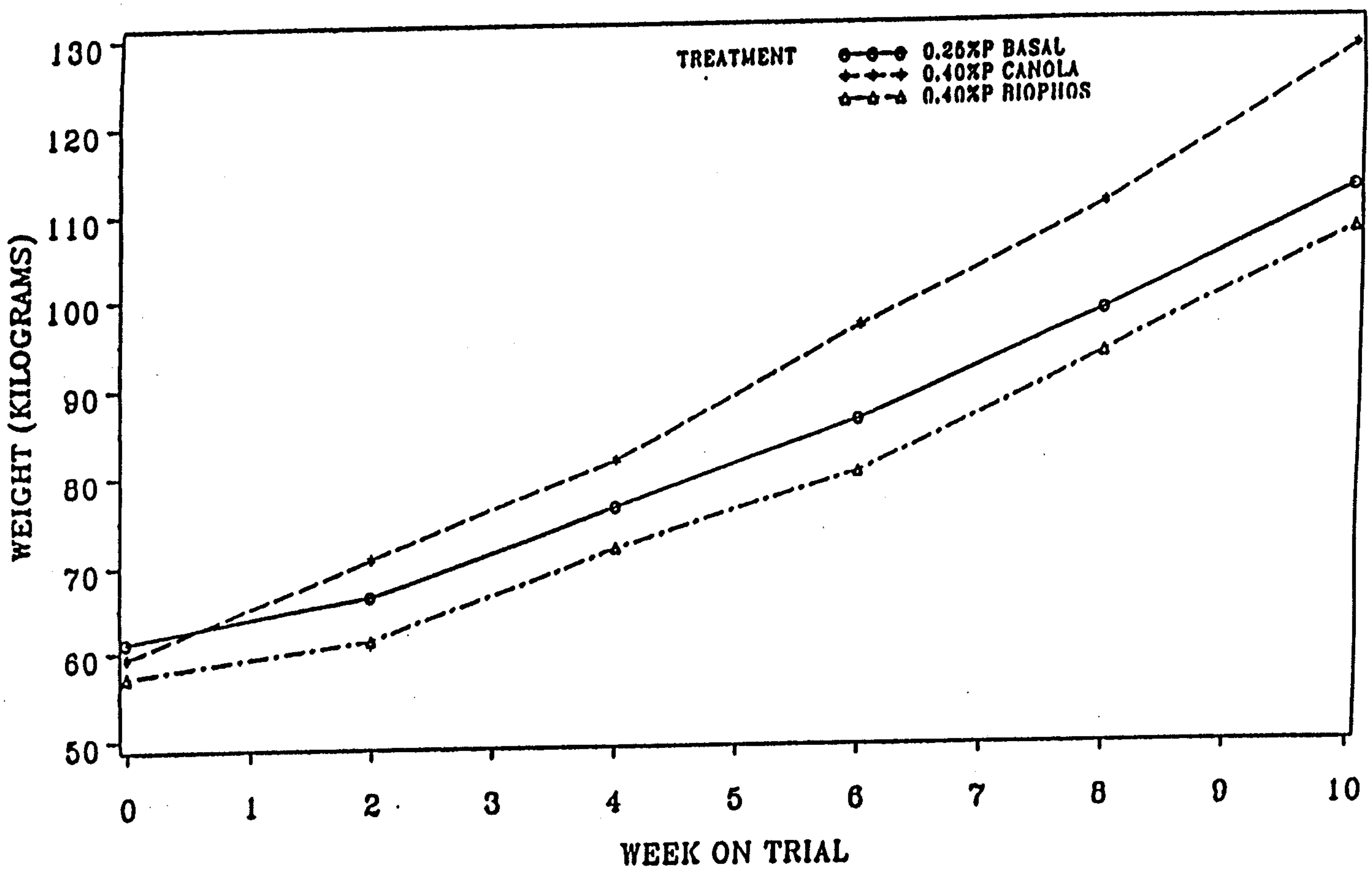


Figure 7. The liveweight body change of calves fed 0.40% phosphorus from two sources.

TABLE 8. Coefficients of variation of response criteria used in the study.

Criterion	%
Dry matter consumption	9.4
weight gain	20.7
feed/gain	16.5
plasma calcium	13.0
plasma inorganic P	12.9
rib ash	3.8
P in ash of bone	5.6
Ca in ash of bone	5.5
Breaking force	14.5

from 0.23 to 0.32 and 0.41% with weight gains of 1.0 kg/day. Daily gains in the present trial ranged from 0.82 to 1.07 for the various treatments with an average of 0.9 kg (Table 7).

There were no significant differences in feed:gain ratio's (Table 6). This is in agreement with the results of Webb et al. (1975) who reported no significant difference in feed:gain ratios when dietary P was increased from 0.1% to 0.2%. Similarly, Miller et al. (1987) reported no significant differences in feed conversion efficiency when dietary P was increased from 0.14, 0.2 and 0.32%. Wise et al. (1958) however, reported improved feed:gain ratios when dietary P was supplemented from 0.14 to 0.22, 0.3 and 0.38%.

The net energy gain content of experimental diets (Table 3) was higher than recommended by NAS-NRC (1988 table 6-5). Making the assumption that the average calf weight from 4-10 weeks of the experiment was 96 kg, then according to NRC (1988 table 6-2) for large breed growing males the requirement for NEm and NEg were calculated. The calculated NEm and NEg values for the diets (Table 3) along with actual intakes were used to compare expected weight gain (Table 7) vs actual weight gain based on amount of NEg left for gain after maintenance energy requirements had been met. Calves on the control diet gained 98% of expected while on average the CM calves gained 110% and Biophos calves gained 106% of expected, suggesting some advantage for the P supplemented calves. The assumption was made that the level of protein in the control, 0.32% P-CM diet and the Biophos supplemented diets was adequate for expected growth rates. Thomas and Tinnimit (1976) fed Holstein calves weaned at about 6 weeks dietary protein levels of 10, 12, 14 and 16% (air dry) from a SBM mixed ration and reported no significant differences in growth rate among the 12, 14, and 16% dietary CP levels however, calves fed 10% CP had less gain (154g/day). Jones et al. (1974) fed Holstein bull calves weaned at four weeks dietary CP levels of 10, 14 and 18% (DM basis). They also reported significantly lower average daily gains for the 10% CP diet but not between 14 and 18%. Ingalls and Devlin (1970) also reported no significant differences in weight gain or feed conversion efficiency for dairy heifers fed diets containing 12 or 15 percent crude protein (as fed basis). Recent data (Ingalls et al. 1989) with young growing Holstein calves fed 13.4 to 16.3% CP (as fed) reported no significant differences in gain, intake or feed/gain ratios. These data suggest that protein was not limiting growth in the present experiment. On average the supplemented groups gained 8% more than expected (Table 7) based on calculated NEm and NEg requirements and intake whereas control calves gained 2% less than calculated. The actual consumption of crude protein ranged from 80-91%

(Table 7) of the requirement according to NAS-NRC table 6-2 (1988). Control calves consumed 91% of requirement. With the increasing supplementation of CM, crude protein consumption increased from 82% to 95% of the NAS-NRC requirement and Biophos supplemented calves consumed 80-90% of requirement. The undegraded intake protein (UIP) is that protein that escapes rumen fermentation and when digestible becomes available for absorption by the tissues from the small intestine (NAS-NRC 1988). The UIP content (Table 3) of the diets were calculated using NAS-NRC table 7-3 (1988). All the experimental diets were below recommended NAS-NRC table 6-5 (1988) levels for 3-6 month old calves. Intake of UIP (Table 7) ranged from 35-40% of that required for 96kg calves using actual weight gains from the 4-10 week period (NAS-NRC table 6-2, 1988) with weight gains of 98 to 110% of expected based on energy intake and 80 to 95% of expected based on crude protein intake, the NAS-NRC (1988) values and/or requirement for UIP must be in error. It is possible that since the diets were pelleted and thus heated there may have been some small increase in UIP. Unpublished data on a dairy cow grain (Ingalls-Omole, University of Manitoba, Personal communication) mixture using the same pelleting procedure would suggest no change in protein degradability with pelleting of the canola meal supplement. R. Campbell (1990, unpublished thesis) using a canola meal-barley diets reported calves at 100 kg consumed 61% of NAS-NRC (1989) required of UIP on a calculated basis from NAS-NRC Table 7-3. Actual rumen degradability data suggested consumption equal to 39.8% of NAS-NRC requirement suggesting that the calculations for UIP may be in error. The degraded intake protein (DIP) of all experimental diets was much higher (Table 3 and Table 7) than NAS-NRC 1988 recommended levels. Degraded intake protein is broken down in the rumen to give available nitrogen and an efflux of ammonia. The available nitrogen may be incorporated into microbial protein whereby the digestible portion of the bacteria becomes available for absorption by the lower GI tract.

Dietary P levels had a significant effect on plasma inorganic P concentration (Table 9). Several research studies have indicated that plasma inorganic P levels are indicative of dietary P levels (Arrington et al. 1962; Hodgson et al. 1948; Long et al. 1956; Teh et al. 1982 and Wise et al. 1961). The dietary P level before the start of the experiment was used as a covariate to examine whether initial blood P levels affected the expression of treatment differences (Appendix Table 2). There were significant ($p < 0.05$) differences due to initial blood P levels at the start of the experiment (week= 0) but thereafter differences were not significant. Plasma inorganic P levels appeared to decline during the initial two weeks for calves on all treatments (Fig. 8, 9, 10).

TABLE 9. Effect of dietary phosphorus level on the concentration of calcium and phosphorus in blood plasma.[1]

	Dietary Treatment							
	0.25% P	0.32% P		0.36% P		0.40% P		
Parameter	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos	± S.E.[2]
Plasma P mg/100 ml								
0-4 weeks	9.18^{d} (0.37)	10.02^{c}	10.3^{c}	10.68^{b}	9.79^{c}	11.49^{a}	9.87^{bc}	0.34
4-10 weeks	8.29^{d} (0.37)	9.20^{c}	9.3^{c}	10.69^{b}	10.22^{c}	11.94^{a}	10.57^{bc}	0.34
0-10 weeks	8.73	9.61	9.79	10.69	10.09	11.73	10.22	
Plasma Ca mg/100 ml								
0-10 weeks	11.1 (0.27)^{ab}	11.6^{a}	11.1^{ab}	11.1^{ab}	10.5^{b}	11.1^{ab}	10.4^{b}	0.25

[1] Least squares means.

[2] Standard error of the mean with six animals per treatment except for the control, which had five animals.

[abc] Means within the same row with different letters are significantly different ($P<0.05$).

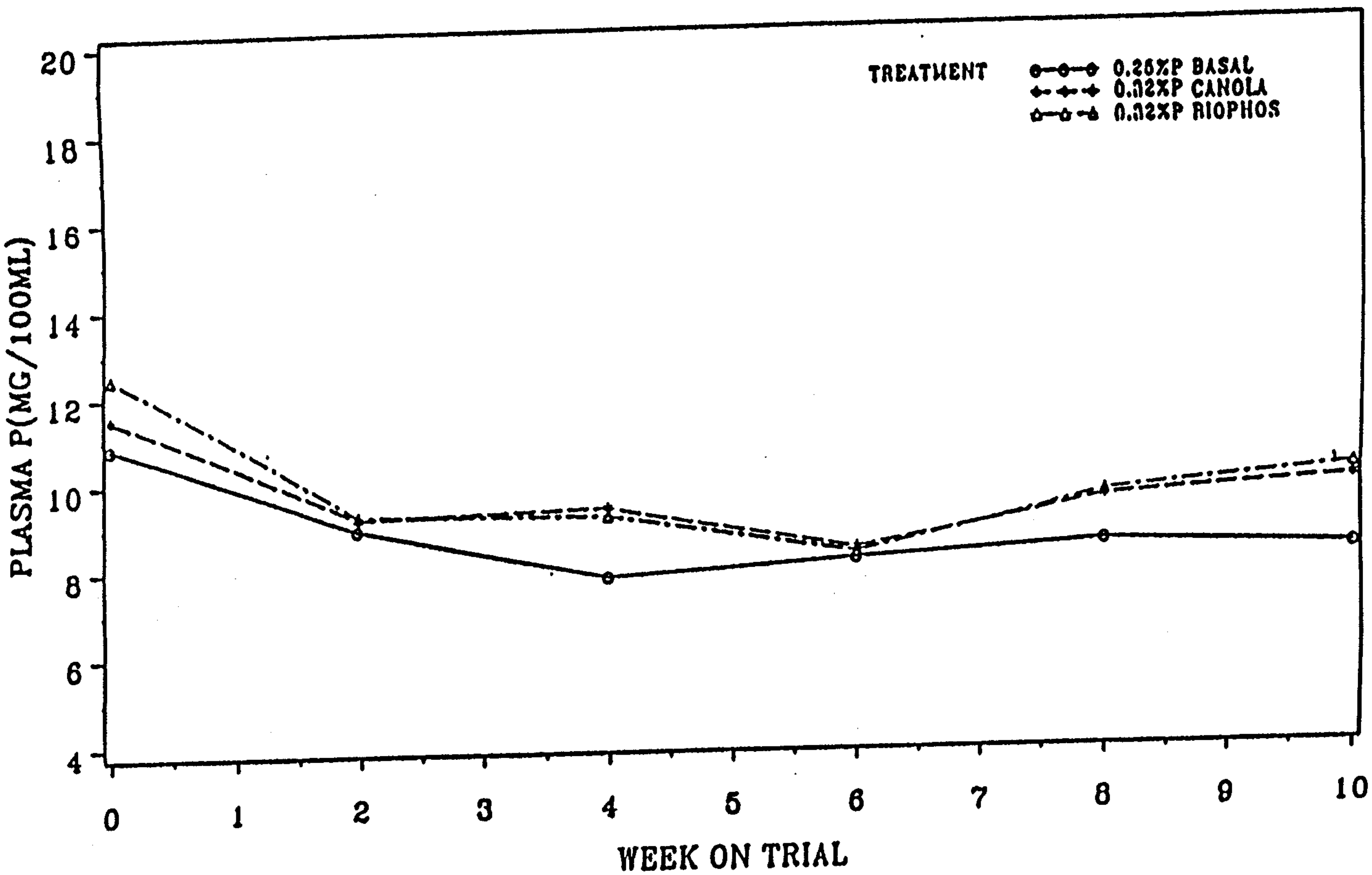


Figure 8. Average biweekly plasma inorganic phosphorus concentration of calves fed 0.32% phosphorus from two sources.

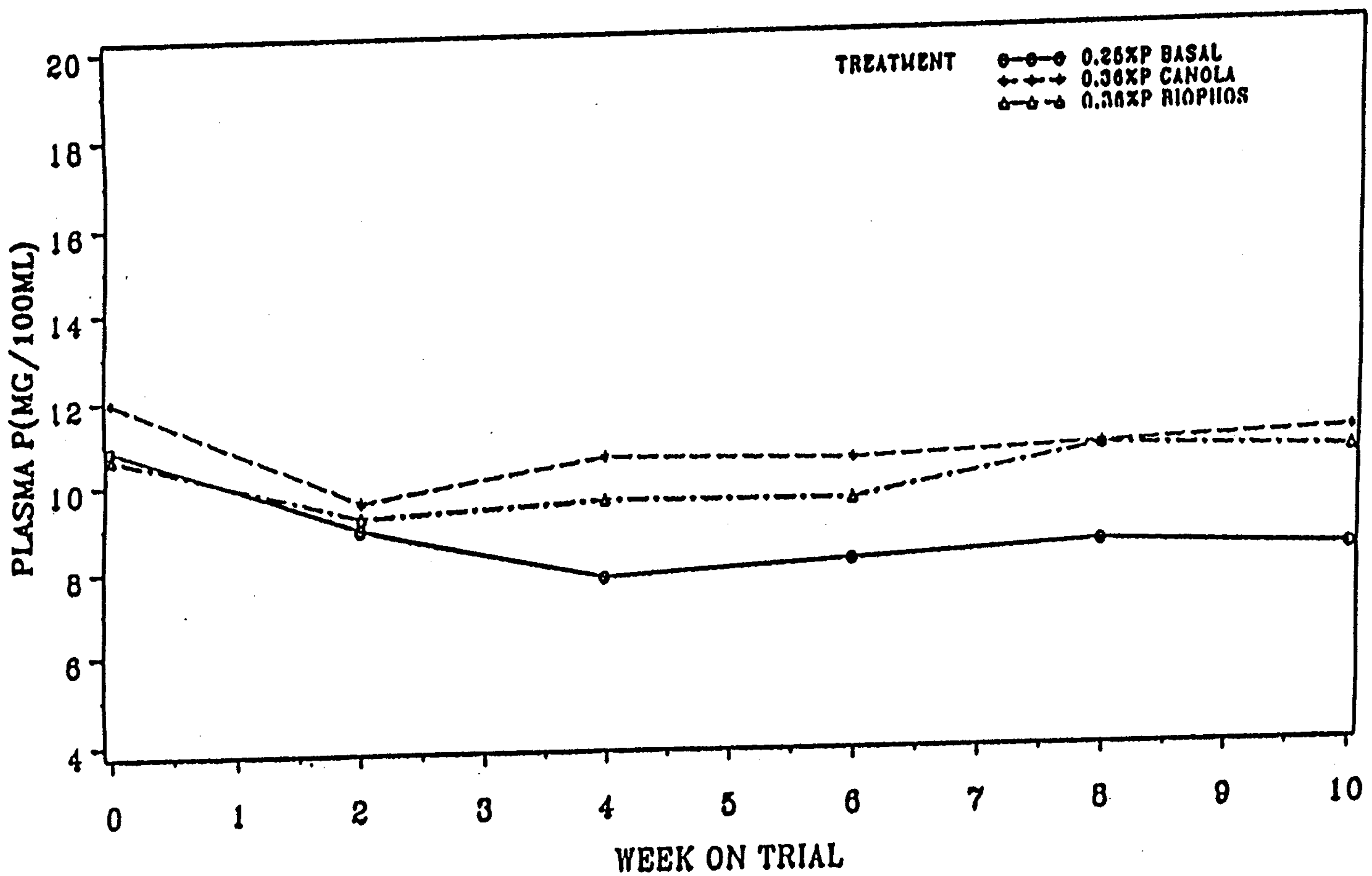


Figure 9. Average biweekly plasma inorganic phosphorus concentration of calves fed 0.36% phosphorus from two sources.

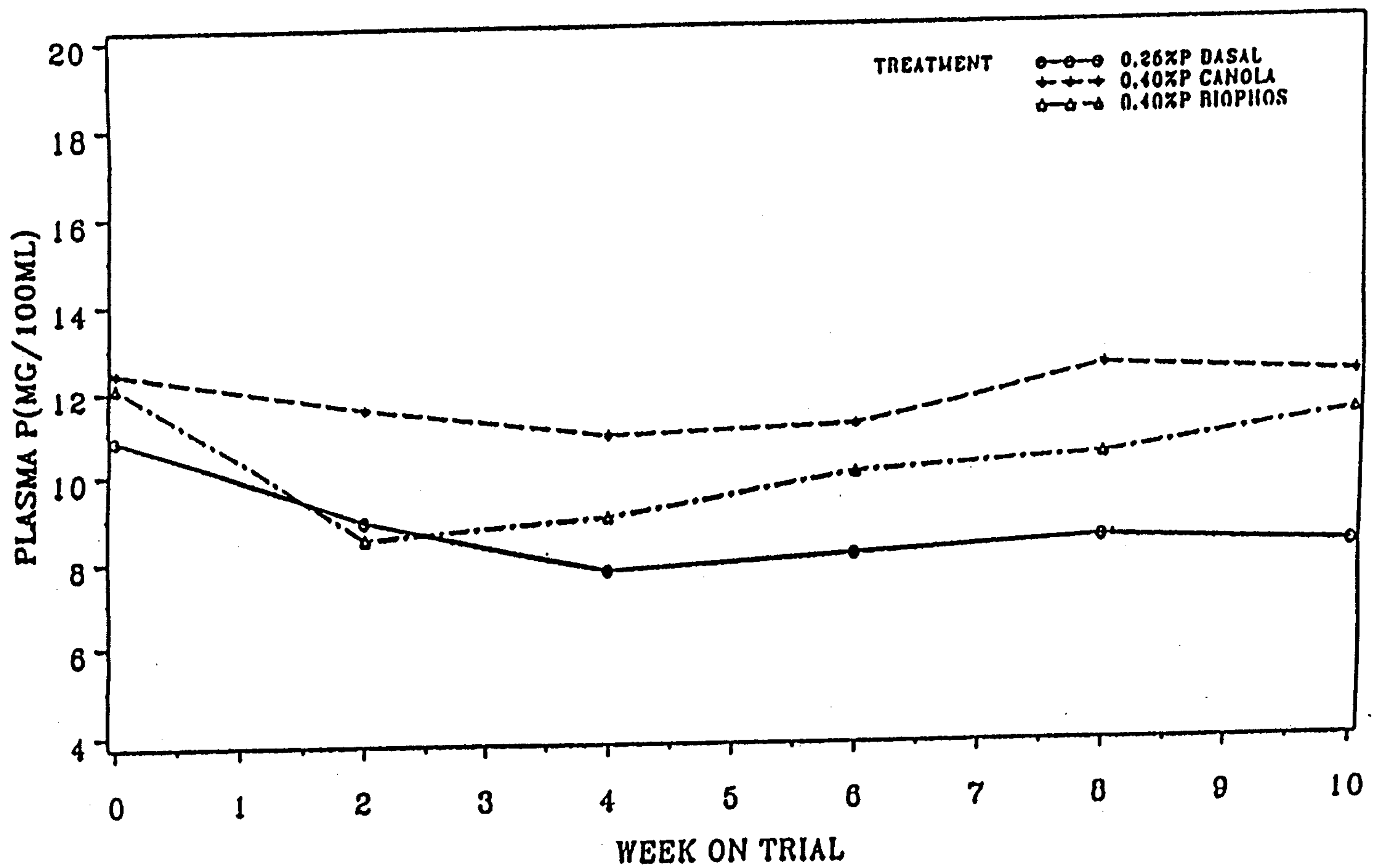


Figure 10. Average biweekly plasma inorganic phosphorus concentration of calves fed 0.40% phosphorus from two sources.

Wise et al. (1958) with no depletion period also observed a decline in serum inorganic P concentration from an initial value of 7mg/100ml with P intakes considered adequate. Miller et al. (1987) at the begining of a four-week depletion period reported an average serum inorganic P level of 5.6mg/100ml which had declined to 2.8 at the end of the depletion period with a diet containing 0.08% P. In the present study the average initial plasma inorganic P levels for all treatments was 13mg/100ml. This high initial level of P may have been due to the P rich diets fed to the calves before the start of the experiment. Some research studies on availability of P have been conducted with a preliminary depletion period where a very low P diet was fed prior to initiating the experiment so that body P stores would be depleted. Langer et al. (1985) conducted a study without a depletion period whereas Teh et al. (1982) had a two week depletion period where a 0.16% P diet was fed yet conclusions drawn from both studies were similar. Plasma inorganic P concentrations were significantly ($p < 0.05$) increased for the CM supplemented diets with each increase in P level to 0.40% but only significantly increased to 0.32% with the inorganic source (Table 9). The plasma P levels continued to increase with the higher levels of Biophos for the 4-10 week data but the differences were not significant ($p > 0.05$). Ternouth and Serville (1983) and Milton and Ternouth (1985) reported that dry matter intake and thus quantity of P consumed was directly related to plasma inorganic P levels. The observed trend towards higher feed consumption (Table 6) with the CM supplemented diets as dietary P was increased to 0.4% may explain the slightly higher plasma P levels for calves on the CM diets compared with those receiving the Biophos supplemented diets. Dietary P consumption (Table 7) by calves on the CM vs Biophos diets would tend to support the above.

The average plasma calcium concentration was not significantly ($p > 0.05$) affected by dietary P levels (Table 9; Fig. 11, 12, 13) except for the lower ($p < 0.05$) plasma calcium levels of calves fed the Biophos 0.36% P and 0.40% P diets compared with calves fed the .32% P canola meal diet. The calcium consumption (Table 7) however was not different and no explanation can be provided for significantly lower blood calcium values observed.

The breaking strength of the eighth and ninth ribs were not significantly different ($p > 0.05$) among treatments (Table 10). However, with the eighth rib and ninth rib canola diets ($p = 0.1$) there was a trend towards a higher breaking strength with P supplemented diets. These results support those of Teh et al. (1982) who reported significantly higher breaking force in eighth and ninth rib bones of dairy calves fed 0.31% as compared to those fed 0.24% P. Similarly, Jackson et al. (1988) observed that

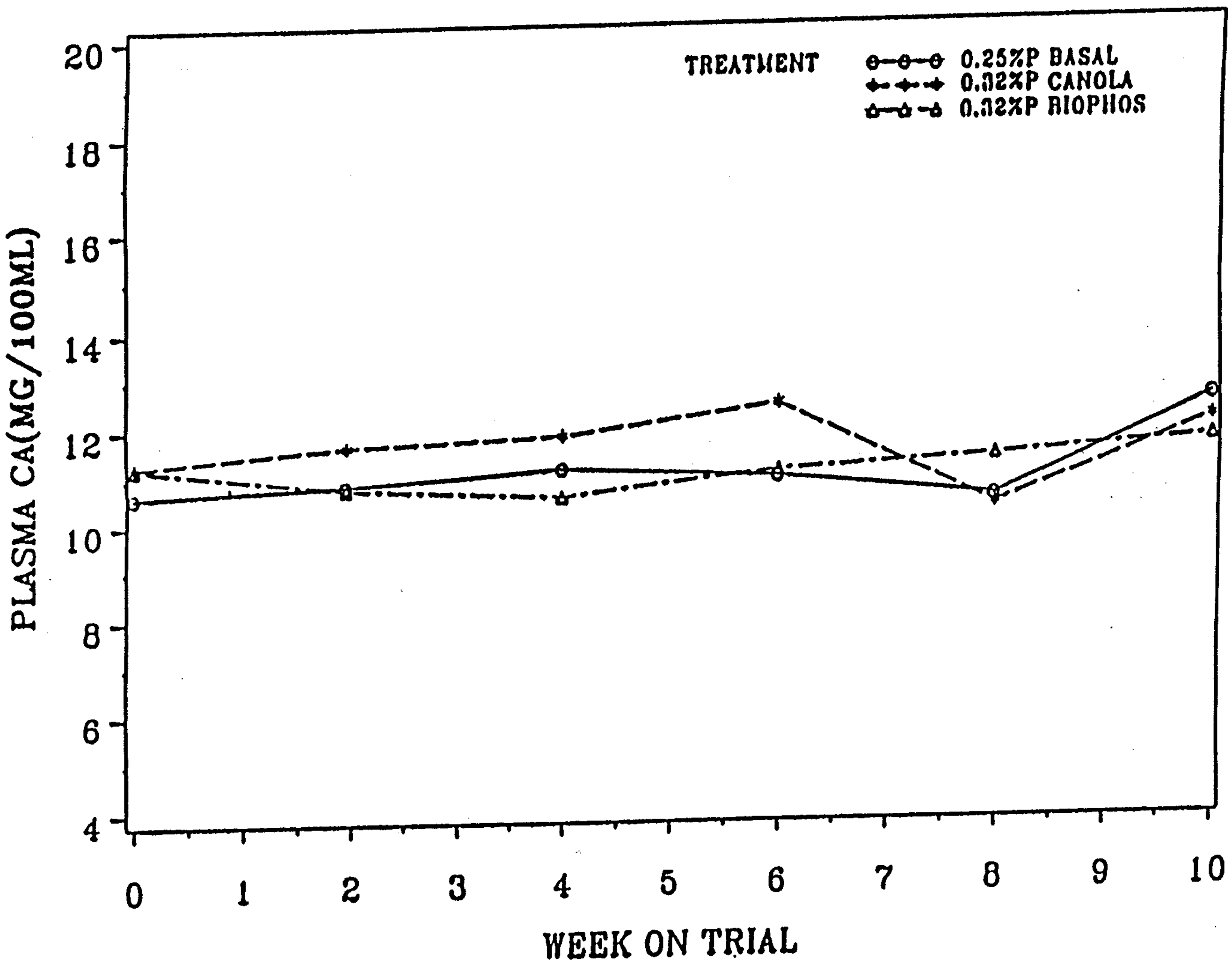


Figure 11. Average biweekly plasma calcium concentration of calves fed 0.32% phosphorus from two sources.

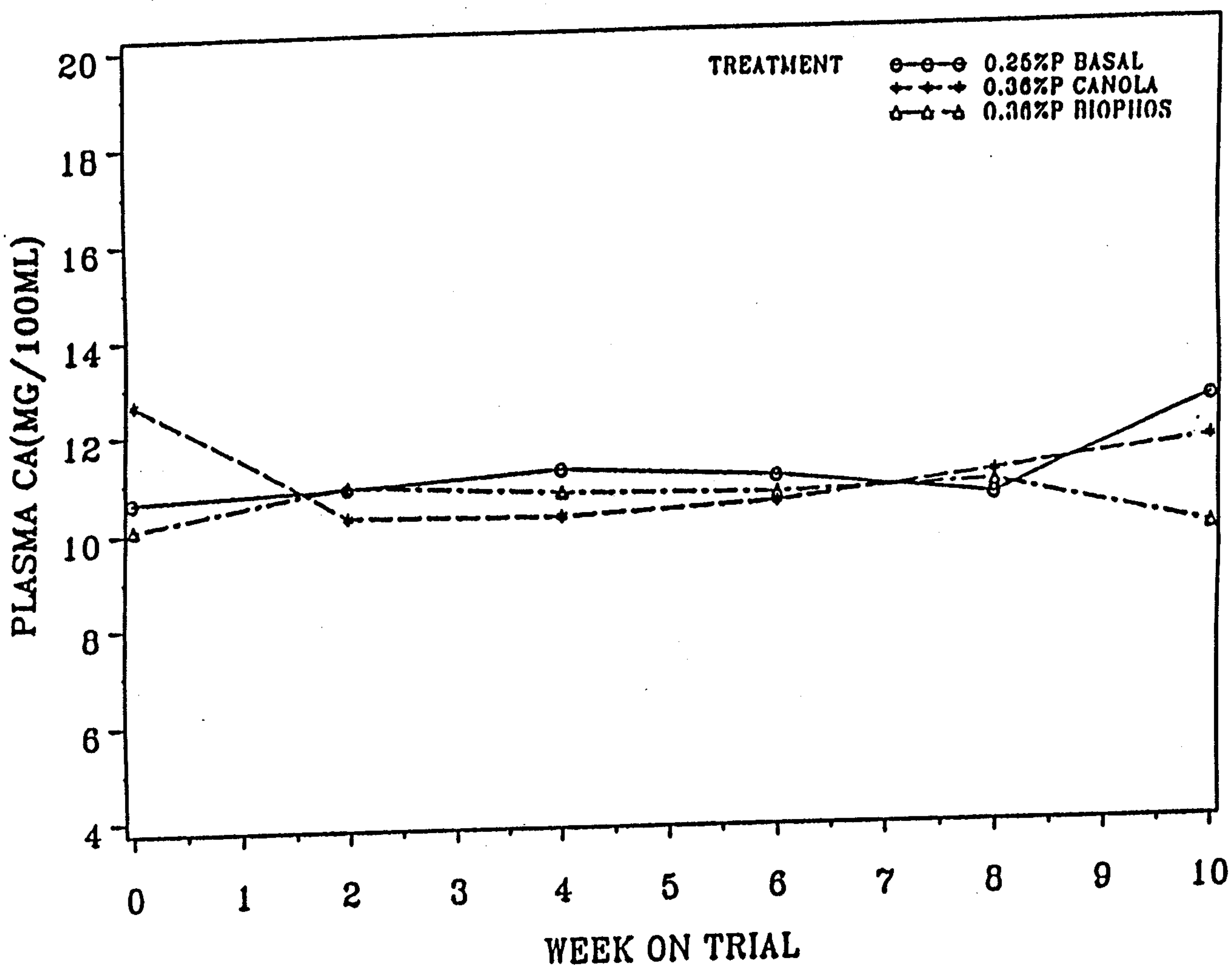


Figure 12. Average biweekly plasma calcium concentration of calves fed 0.36% phosphorus from two sources.

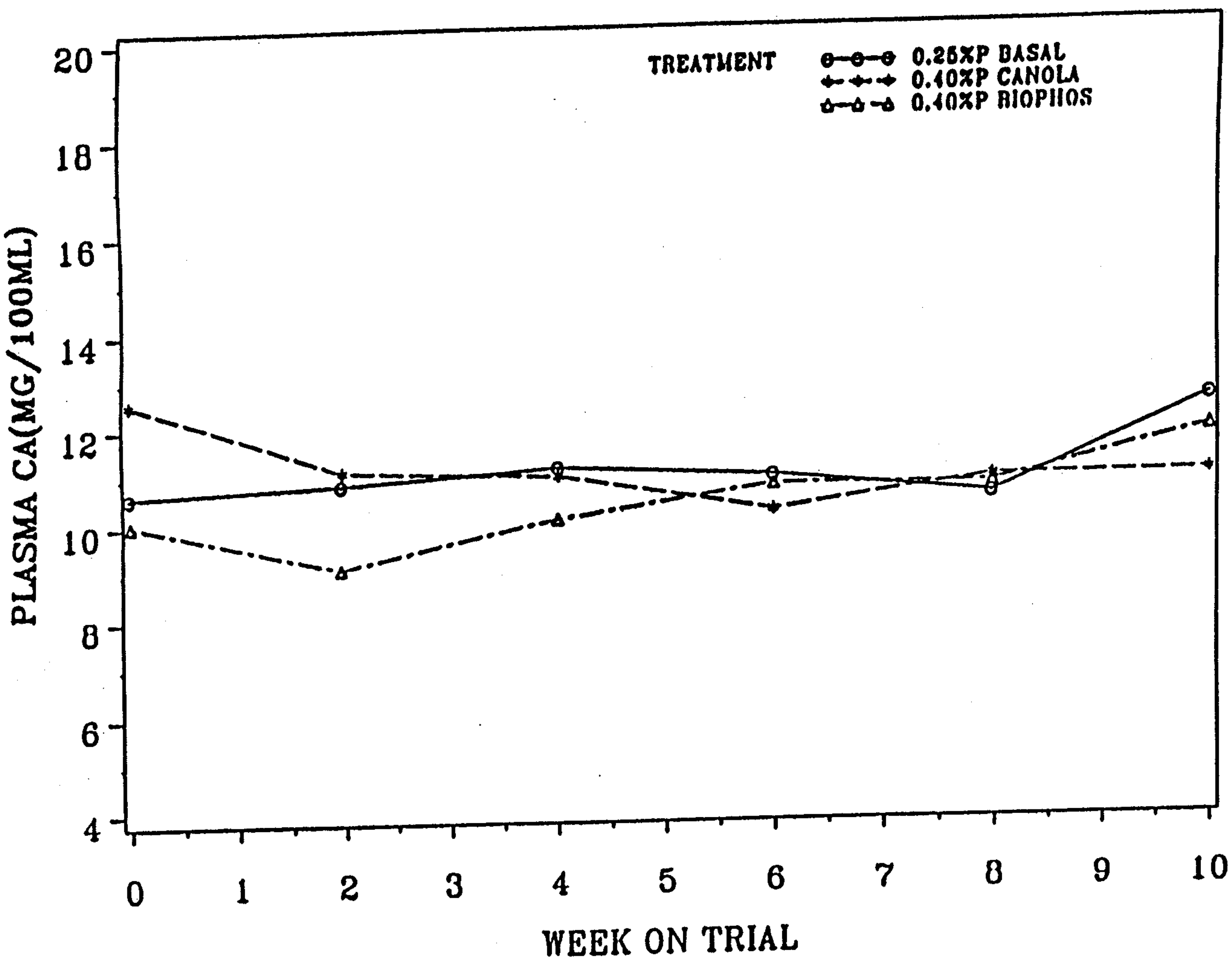


Figure 13. Average biweekly plasma calcium concentration of calves fed 0.40% phosphorus from two sources.

TABLE 10. Effect of dietary phosphorus on the breaking force, bone ash, bone calcium and bone phosphorus of the eighth and ninth ribs of male Holstein calves.[1]

Parameter	0.25% P Control	0.32% P Canola	0.32% P Biophos	0.36% P Canola	0.36% P Biophos	0.40% P Canola	0.40% P Biophos	± S.E.[2]
Breaking force, N[3]								
Eighth rib	163.1 (12.6)[4]	197.5	218.9	246.4	213.6	236.0	198.2	11.5
Ninth rib	151.0 (12.6)	159.5	151.5	214.7	178.1	212.3	155.8	11.5
X	157.1	178.5	185.2	230.6	195.9	224.2	177.0	
Bone ash, %								
Eighth rib	49.0 (0.81)	48.7	47.4	47.4	46.4	46.2	45.7	0.75
Ninth rib	48.5 (0.81)	46.5	47.5	46.2	46.7	46.0	46.6	0.75
X	48.8	47.6	47.5	46.8	46.7	46.0	46.6	
P in ash, % eighth rib	8.9 (0.23)	9.0	9.0	9.0	9.2	9.5	9.6	0.21
P in ash, % ninth rib	9.4 (0.23)	9.3	9.2	9.4	9.4	9.2	9.4	0.21
X	9.2	9.2	9.1	9.2	9.3	9.4	9.5	
Ca in ash, % eighth rib	17.5 (0.45)	17.4	18.2	17.9	19.0	19.2	18.6	0.41
Ca in ash, % ninth rib	17.7 (0.45)	18.1	17.6	17.9	17.7	17.8	18.4	0.41
X	17.6	17.8	17.9	17.9	18.4	18.5	18.5	

[1] Least squares means.

[2] Standard error of the mean with six animals per treatment except for the control, which had five animals.

[3] N = Newton where 1N = 10 kg.

[4] Numbers in parenthesis indicate the standard error for the control.

increasing dietary P from 0.26 to 0.34% significantly increased the bending moment of the tibia and ninth rib. No further increase occurred when P was supplemented to 0.41%.

No significant ($p > 0.05$) effect of dietary P on rib ash percentages were observed in both the eighth and ninth ribs (Table 10). No significant ($p > 0.1$) rib and dietary P interaction occurred indicating that the response to dietary P was similar for both the eighth and ninth ribs. In a study by Little (1984) animals were slaughtered and dissected and total body P measured among muscles, viscera, blood, skin, sternum/coastal cartilage, appendicular, axial and rib bones. They reported the rib was the most responsive to P deficiency since the concentration of P in total fresh rib was 5.4% and 4.5% for the diets designated as high and low respectively. There were no significant ($p > 0.05$) differences among treatments in bone ash, bone calcium and bone P (Table 10). This is consistent with the results of Wise et al. (1961) and Miller et al. (1987). Teh et al. (1982) however, reported significantly higher bone ash content when dietary P level was increased from 0.24 to 0.31% even though bone calcium and bone P were not different. Wise et al. (1958) also reported a significant increase in bone ash content of the ninth rib when dietary P was increased from 0.14, 0.22 to 0.30%. No further improvement occurred at a supplementation of 0.38%. These results are in agreement with those of Jackson et al.

(1988) who reported a significant increase in bone ash and bone P content of the seventh and tenth rib as dietary P was increased from 0.24 to 0.34%. Supplementation to 0.41% resulted in no further improvement. No significant difference in bone calcium however was observed. The failure for the treatment differences to show significance for the breaking force of the eighth rib may have been due to the high individual animal (Table 8) variation (c.v.= 14.5%).

<u>In situ measurement of phosphorus disappearance</u>

Phosphorus disappearance from CM and SBM measured using nylon bags suspended in the rumen was significantly ($p < 0.05$) higher for SBM than for CM samples B, D and E at 12 and 16 h of incubation. Although, a lower level was found for samples A and C, they were not significantly different from SBM (Table 11, Fig. 14). The degradation of DM at 12 h was not different ($p > 0.05$) for SBM and CM samples (Appendix Table 5). Disappearance of DM (Kendall 1988) for CM samples B and D was less ($p < 0.05$) than that of CM sample C (40 and 37 vs 47%). This trend was also noted for P (Table 11). Differences in processing techniques of the CM samples may affect degradability in the rumen, since the samples were obtained from five different processors. Although, direct comparisons cannot be made since the 12 h and 16 h trials were carried out on different days more P

TABLE 11 Rumen, lower gastrointestinal tract, pepsin digestion and total gastrointestinal tract in situ phosphorus disappearance (%).

Parameter	A-CM	B-CM	C-CM	D-CM	E-CM	F-SBM	± S.E.
Rumen incubation							
12 h	52.5[ab]	42.3[bc]	50.0[ab]	36.4[c]	46.8[bc]	60.2[a]	1.39
16 h	77.5[a]	65.3[b]	69.7[ab]	66.5[b]	63.9[b]	77.3[a]	1.23
Lower GI tract[2]							
12 h rumen incubation followed by pepsin & HCl digestion.	89.7	93.7	89.4	90.2	90.2	88.9	1.32
Pepsin digestibility[3]	83.6	80.9	73.4	72.7	78.8	86.0	1.47
16 h rumen incubation and no pepsin & HCl digestion.	79.4[b]	78.7[b]	76.8[b]	76.3[b]	76.1[b]	91.0[a]	1.22
Total GI tract							
12 h rumen incubation followed by pepsin & HCl digestion.	95.2	96.3	94.7	93.7	94.7	95.6	1.04
16 h rumen incubation and no pepsin & HCl digestion.	95.3[b]	92.6[b]	92.9[ab]	92.0[b]	91.4[b]	97.9[a]	0.86

[1] Standard error of the mean.
[2] phosphorous disappearance from rumen fermentation residue
[3] % of rumen digested by pepsin
[a,b,c] Means within the same row with different subscripts are significantly different ($p < 0.05$).

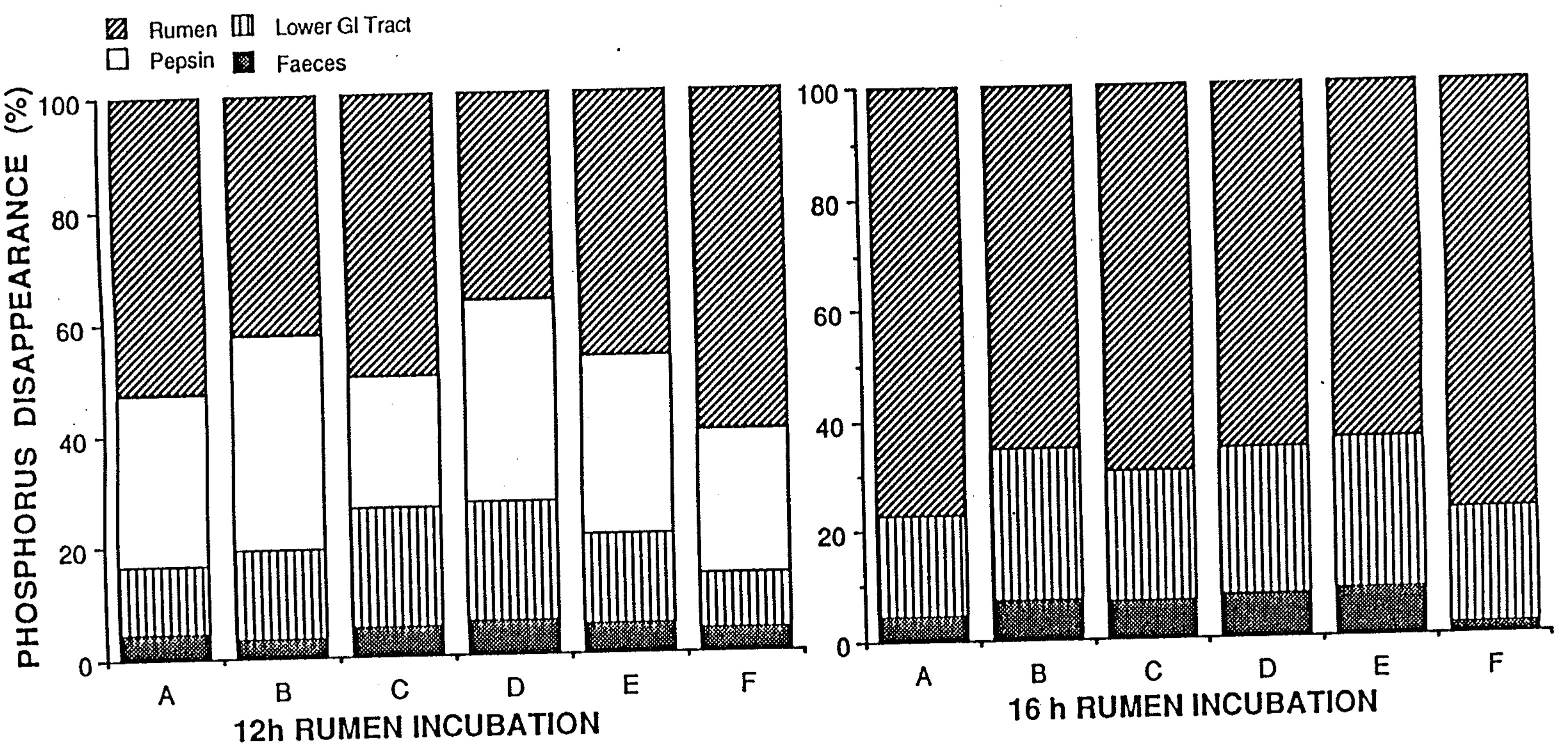


Fig. 14. The phosphorus disappearance from the rumen and lower gastrointestinal tract of canola meal samples A, B, C, D, E and SBM (F) at 12 and 16 h of rumen incubation.

disappeared at 16 h of rumen incubation as one would expect. Ha and Kennelly (1984) reported significant differences in DM disappearance between CM and SBM (57.7% and 51.9% respectively) when incubated in the rumen for 12 h. At 24 h of incubation there were no significant differences between SBM and CM (74.1% and 70.6% respectively).

The digestion of P from rumen incubated samples in the lower GI tract was not significantly ($p > 0.05$) different for SBM and CM at 12 h for samples predigested with 1% pepsin-HCl prior to insertion into the duodenum (Table 11; Fig. 14). Kendall (1988) using similar CM samples reported no significant differences in lower tract DM disappearance among canola meal sample at 12 h of rumen incubation and all CM samples resulted in less DM disappearance than SBM (Appendix Table 5). With no pepsin-HCl predigestion of the 16 h rumen incubated samples, P disappearance in the rumen was higher ($p < 0.05$) for SBM than all the CM samples in the lower GI tract. There was a similar trend for DM disappearance but canola meal sample B was lower ($p < 0.05$) than that of canola meal samples D and E (Appendix Table 5). Phosphorus disappearance appeared higher than that of DM especially for the 16h incubation period. The levels of P and DM disappearance appeared to follow similar trends among the CM and SBM samples.

The total tract digestion of P was not significantly different (p > 0.05) for SBM and CM for those samples predigested with pepsin-HCl prior to insertion into the duodenum (Table 11; Fig. 14). At 16 h of rumen incubation without pepsin-HCl digestion, total tract P digestibility was significantly (p < 0.05) higher for SBM than for the CM samples B, C, D, E (Table 11). The values for the 12 h rumen incubation samples for "true" disappearance of P compared well with the results of Preston and Pfander (1964) who reported apparent digestibility of P in dicalcium phosphate of 90-93%. Lofgreen et al. (1952) reported true digestibility of P in casein by young calves to be 94%.

SUMMARY

A growth trial with young rapidly growing calves was used to evaluate the availability of P from CM relative to Biophos. Dry matter consumption was not significantly increased with increasing supplementation of dietary phosphorus from either source, although a trend towards increased consumption with supplementation of CM diets from a dietary level of 0.32 to 0.36% was observed. There were no significant increases in weight gain due to increased supplementation with P; however, a trend towards higher gain among CM supplemented diets was observed. The plasma inorganic P concentration was significantly increased up to 0.40% P with increasing levels of P from CM and up to 0.32% P with Biophos supplementation. If blood plasma inorganic P levels are taken as a measure of dietary P availability then the availability of P from CM was at least equal to that of the inorganic source.

No significant effects ($p > 0.05$) of dietary P levels on rib ash, bone calcium and bone phosphorus percentage were observed. The breaking force of the eighth and ninth ribs were not significantly ($p > 0.05$) affected by dietary P supplementation. There was a trend towards a higher breaking force for the CM supplemented diets up to a dietary level of 0.36% for the eighth rib bone, which seemed to indicate the absorbed P was being deposited in

bone. In situ phosphorus disappearance from the rumen was significantly higher for SBM than for three of the five CM samples at 12 h and 16 h of rumen incubation.

The **in situ** phosphorus disappearances from CM in the lower GI tract appeared to be reduced when the samples were not predigested with pepsin-HCl. This was not true for SBM. The **in situ** P disappearance from the total tract was not significantly different between SBM and CM when pepsin-HCl digestion was used. These data indicate that the higher concentration of P in CM is digested equally as well as that in SBM.

CONCLUSIONS

1. On the basis of plasma inorganic phosphorus concentrations, phosphorus availability from canola meal is at least equal to that of Biophos.

2. The total gastrointestinal tract availability of phosphorus from 5 different canola meal samples was equal to that of a soybean meal sample as measured by the mobile nylon bag technique when samples were digested with pepsin-HCl prior to entering the gastrointestinal tract.

3. Recommendations for future research include a longer experimental period of 14-16 weeks so that perhaps some differences may be manifested.

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Appendix Table 1. Average daily protein intake, dry matter intake and gain for the experimental diets.

Parameter	Dietary Treatments						
	0.25% P	0.32% P		0.36% P		0.40% P	
	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos
Daily CP intake, g 1-10 weeks	295.0	301.4	282.8	351.1	270.0	387.1	277.1
Daily gain, g 0-10 weeks	631.4	684.3	698.6	724.3	621.4	765.7	600.0
Daily DM intake, kg 1-10 weeks	1.90	1.90	2.01	2.10	1.84	2.17	1.83

Appendix Table 2. The analysis of covariance for plasma inorganic phosphorus concentration using initial blood phosphorus levels(halftst) as the covariate

WEEK=0

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	29.39514573	4.19930653	2.56	0.0341	0.373978	10.9514
ERROR	30	49.20605430	1.64020181		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	78.60120004			1.28070364		11.69444368

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	18.25619075	1.86	0.1218	6	13.02019916	1.32	0.2776
HALFTST	1	11.13895498	6.79	0.0141	1	11.13895498	6.79	0.0141

WEEK=2

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	48.41927829	6.91703976	3.26	0.0107	0.432325	15.4108
ERROR	30	63.57803587	2.11926786		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	111.99731416			1.45577054		9.44641053

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	39.48474148	3.11	0.0174	6	46.02741908	3.62	0.0081
HALFTST	1	8.93453681	4.22	0.0489	1	8.93453681	4.22	0.0489

WEEK=4

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	31.68474092	4.52639156	2.93	0.0184	0.406114	13.0993
ERROR	30	46.33456685	1.54448556		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	78.01930777			1.24277333		9.48732632

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	31.09812136	3.36	0.0119	6	31.61156296	3.41	0.0110
HALFTST	1	0.58661956	0.38	0.5424	1	0.58661956	0.38	0.5424

WEEK=6

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	47.01168367	6.71595481	3.09	0.0141	0.419126	15.4164
ERROR	30	65.15442441	2.17181415		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	112.16610809			1.47370762		9.55933026

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	46.52936832	3.57	0.0087	6	46.61042086	3.58	0.0086
HALFTST	1	0.48231535	0.22	0.6409	1	0.48231535	0.22	0.6409

WEEK=8

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	56.04514447	8.00644921	2.69	0.0275	0.385455	16.7828
ERROR	30	89.35479283	2.97849309		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	145.39993730			1.72583113		10.28331816

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	56.04507049	3.14	0.0166	6	55.08581004	3.08	0.0180
HALFTST	1	0.00007398	0.00	0.9961	1	0.00007398	0.00	0.9961

WEEK=10

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PLP

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	7	65.48280055	9.35468579	5.27	0.0005	0.551607	12.6435
ERROR	30	53.22997327	1.77433244		ROOT MSE		PLP MEAN
CORRECTED TOTAL	37	118.71277382			1.33204071		10.53541053

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
TRT	6	65.41991842	6.15	0.0003	6	63.62707356	5.98	0.0003
HALFTST	1	0.06288212	0.04	0.8519	1	0.06288212	0.04	0.8519

Appendix Table 3. The net energy, undergradability and calculations of the undegradable and degradable protein contents of ingredients used in the experimental diets on an as fed basis.

Ingredient	NEm MCal/kg	NEg MCal/kg	Protein fed %	Under-gradability[1] %	Control protein kg	Control UIP kg	.32 Canola protein kg	.32 Canola UIP kg
Alfalfa dehydrated	1.24	0.71	16	59	6	.566	6	.566
Beet pulp	1.71	1.13	7.8	45	23	.807	23	.807
Brewers dried grains	1.4	0.85	27.9	49	8	1.094	8	1.094
Corn starch	2.2	1.52	0.6	--	30.6	--	26	--
Corn grain	1.87	1.27	8.7	52	15.7	.710	15.7	.710
Molases cane dried	1.52	0.96	--	--	3.0	--	3.0	--
Soybean meal	1.89	1.28	48	35	11.7	1.966	11.7	1.966
Urea			281	0	0.44	0	0	--
Fat 5.81	5.81	5.81	0	0	0	0	0.6	--
Canola meal	1.58	1.01	36	28	0	0	5.0	.504

Ingredient (continued)	.32 Biophos protein kg	.32 Biophos UIP kg	.36 Canola protein kg	.36 Canola UIP kg	.36 Biophos protein kg	.36 Biophos UIP kg	.40 Canola protein kg	.40 Canola UIP kg	.40 Biophos protein kg	.40 Biophos UIP kg
Alfalfa dehydrated	6	.566	6	.566	6	.566	6	.566	6	.566
Beet pulp	23	.807	23	.807	23	.807	23	.807	23	.807
Brewers dried grains	8	1.094	8	1.094	8	1.094	8	1.094	8	1.094
Corn starch	30	--	21	--	30.4	--	15	--	30.2	--
Corn grain	15.7	.710	15.7	.710	15.7	.710	15.7	.710	15.7	.710
Molases cane dried	3.0	--	3.0	--	3.0	--	3.0	--	3.0	--
Soybean meal	11.7	1.966	11.7	1.966	11.7	1.966	11.7	1.966	11.7	1.966
Urea	.44	--	--	--	.44	--	--	--	.44	--
Fat	--	--	.06	--	--	--	1.71	--	--	--
Canola meal	--	--	10.0	1.008	--	--	15.0	1.512	--	--

[1] NRC 1988 Table 7-3

Appendix Table 4. Diet calculated protein intakes, experimental and actual daily weight gains.

	Dietary Treatments						
	0.25% P	0.32% P		0.36% P		0.40% P	
	Control	Canola	Biophos	Canola	Biophos	Canola	Biophos
Daily intake (kg as fed)	2.69	2.72	2.82	2.99	2.65	3.02	2.65
Intake required for maintenance[2] (kg)	1.45	1.48	1.45	1.48	1.44	1.47	1.45
Intake remaining for growth (kg)	1.24	1.24	1.37	1.51	1.21	1.55	1.20
Calculated daily gain[3] (kg)	0.83	0.85	0.92	1.01	0.82	1.07	0.81
Experimental daily gain (kg)	0.81	0.99	0.95	1.10	0.90	1.11	0.85
Protein:							
Calculated[4] (%)	13.2	14.5	13.0	15.6	13.6	16.8	14.0
Determined (%)	14.3	15.8	14.1	16.7	14.7	17.9	15.1
Average intake (kg)	15.8	16.6	15.4	19.6	15.2	21.3	15.6
NRC requirement	16.4	20.1	19.1	22.3	18.3	22.3	17.2
Calculated intake UIP[5] (kg)	6.1	6.9	6.3	7.4	6.2	7.9	6.3
NRC requirement (kg)	15.2	18.5	17.8	20.6	16.9	20.8	15.9
Calculated intake DIP[6] (kg)	8.8	9.6	9.2	12.1	8.9	13.4	9.3
NRC requirement DIP (kg)	3.0	3.7	3.6	4.1	3.4	4.2	3.2

1 Diet calculated dry matter intake for 4-10 weeks of the experiment (Appendix Table 2).
2 Diet calculated NEm concentration (Table 3, Appendix Table 4). Average weight of 96 kg used 1988 revised NRC.
3 Diet calculated NEG concentration (Table 3, Appendix Table 4). Average weight of 96 kg used 1988 revised NRC.
4 Appendix Table 3.
5 Appendix Table 3, Table 3.
6 Appendix Table 3, Table 3.

Appendix Table 5. Comparison of an in situ dry matter and phosphorus disappearance at 12 and 16 hours of rumen incubation[1]

	Canola meal samples					
	A	B	C	D	E	SBM
Rumen incubation[2]						
12 h						
Phosphorus	52.5^{ab}	42.3^{bc}	50.0^{ab}	36.4^{c}	46.8^{bc}	60.2^{a}
Dry matter	43.7^{ab}	40.1^{b}	46.9^{a}	37.6^{b}	41.4^{ab}	42.8^{ab}
Difference	8.8	2.2	3.1	-1.8	5.4	17.4
16 h						
Phosphorus	77.5^{a}	65.3^{b}	69.7^{ab}	66.5^{b}	63.9^{b}	77.3^{a}
Dry matter	56.6^{ab}	54.8^{ab}	58.5^{ab}	52.1^{b}	56.5^{ab}	62.3^{a}
Difference	20.9	10.5	11.2	14.4	7.4	15.0
Lower GI tract						
12 h						
Phosphorus	89.7	93.7	89.4	90.2	90.2	88.9
Dry matter	51.8^{b}	56.6^{b}	58.8^{b}	62.0^{b}	48.0^{b}	82.0^{a}
16 h						
Phosphorus	79.4^{b}	78.7^{b}	76.8^{b}	76.3^{b}	76.1	91.0^{a}
Dry matter	39.0^{bc}	29.6^{c}	37.2^{bc}	46.4^{b}	41.6^{b}	84.5^{a}

1 DM disappearance from Kendall (1988)
2 These data were collected from the same animals at the same time